1. Introduction

This Concept of Operations (CONOPS) is a formal document that describes how Washington State Ferries (WSF) proposes to convert the Issaquah class vessels from diesel to liquefied natural gas (LNG) as a source of fuel for propulsion. In brief, WSF proposes a conversion of its Issaquah class vessels that would entail retrofitting LNG tanks on the top decks situated between the exhaust stacks. The retrofit would also entail the installation of associated cryogenic piping. The potential benefits for fuel cost savings and emissions reduction warrant such a proposal for this class of vessels. This CONOPS is a communication vehicle to inform stakeholders of the intended modes of operation and methods of supporting a conversion to LNG. The CONOPS also enables an early assessment of the operational environment. This CONOPS will also be used as a source of information for the development of project planning and decision making.

This CONOPS expresses WSF's vision for deployment and support of the proposed conversion to LNG. This CONOPS is intended to gain consensus among stakeholders on the operating and support concepts, employment, capabilities, and human resource systems needed to make the proposed conversion successful. To achieve consensus, stakeholders must collaboratively balance the desires of the goal of conversion against the realities of technology, budget, schedule and risk. This CONOPS will use operational scenarios to describe, in non-technical terms, a "Day in the Life" of a post conversion Issaquah class vessel. These scenarios are fictional/notional, but are realistic depictions of how Issaquah class vessels will operate and be supported. Development of this CONOPS includes careful consideration of the full range of factors that together are required for a conversion to LNG.

2. Referenced Documents

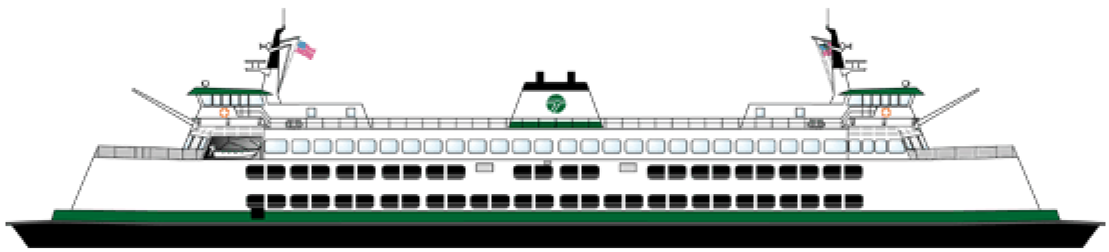
This CONOPS brings together information from numerous WSF studies and the work of consultants' research, as well as open source literature.

Documents used in the preparation of this CONOPS:

- *LNG Use for Washington State Ferries*, March 2010, (Appendix 1)
- *144-Car Ferry LNG Fuel Conversion Feasibility Study*, July 2011, (Appendix 2)
- *144-Car Ferry LNG Fuel Conversion Feasibility Study: Life Cycle Cost Analysis*, July 2011, (Appendix 3)
- *Evaluating the Use of Liquefied Natural Gas in Washington State Ferries*, January 2012, report to Washington State Legislature Joint Transportation Commission, (Appendix 4)
- *NAVIGATION AND VESSEL INSPECTION CIRCULAR (NVIC) NO. 01-11: GUIDANCE RELATED TO WATERFRONT LIQUEFIED NATURAL GAS (LNG) FACILITIES*, January 2011, U.S Coast Guard
- Draft, Washington State Ferries LNG Bunkering Procedure for Issaquah Class Vessels, May 14, 2012 (Appendix 5)

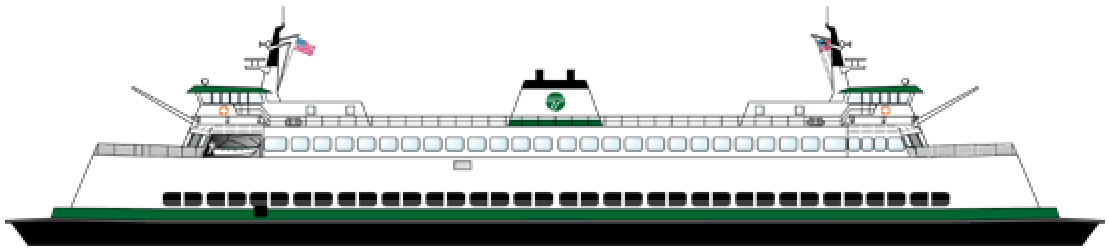
3. Current Situation

WSF currently operates five Issaquah 130 class ferries: M/V Issaquah, M/V Kittitas, M/V Chelan, M/V Kitsap, M/V Cathlamet and one Issaquah class ferry, M/V Sealth. These vessels were built and commissioned in the early 1980s. Originally all these vessels were built to carry 1200 passengers and 100 cars. However, in the 1990s five of the vessels were modified to carry 130 cars, leaving just the M/V Sealth unmodified. The M/V Chelan was upgraded to SOLAS standards in 2005, allowing it to be one of two WSF ferries certified to make the crossing between the United States and British Columbia.



Vessel Specifics 130 Car Class

Class: Issaquah 130	**Type:** Auto/Passenger Ferry
Length: 328'	**Engines:** 2
Beam: 78' 8"	**Horsepower:** 5,000
Draft: 16' 6"	**Speed in Knots:** 16
Max Passengers: 1200	**Propulsion:** DIESEL
Max Vehicles: 130	**Gross Tonnage:** 2477
Tall Deck Space: 26	**City Built:** Seattle
Auto Deck Clearance: 15' 6"	**Year Built / Re-built:** 1981 / 1993



Vessel Specific 100 Car Class

Class: Issaquah	**Type:** Auto/Passenger Ferry
Length: 328'	**Engines:** 2
Beam: 78' 8"	**Horsepower:** 5,000
Draft: 15' 6"	**Speed in Knots:** 16
Max Passengers: 1200	**Propulsion:** DIESEL
Max Vehicles: 100	**Gross Tonnage:** 2477
Tall Deck Space: 30	**City Built:** Seattle
Auto Deck Clearance: 15' 2"	**Year Built / Re-built:** 1982

These vessels have the potential of operating on many of the Washington State Ferry routes. These routes are: Seattle-Bremerton (SR 304), Seattle-Bainbridge Island (SR 305), Southworth to Vashon Island to Fauntleroy (West Seattle) (SR 160), Point Defiance-Tahlequah (south end of Vashon Island) (SR 163), Clinton to Mukilteo (SR 525), Edmonds-Kingston (SR 104), , Anacortes to any or all of the following; Lopez Island, Shaw Island, Orcas Island, Friday Harbor (on San Juan Island), Sidney, British Columbia.

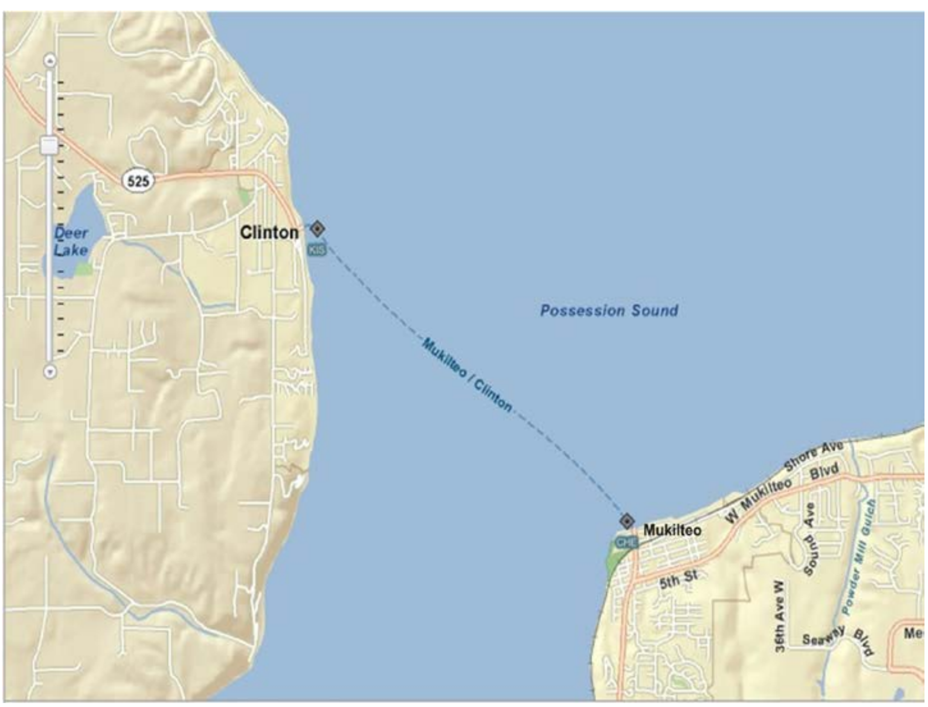
However, these vessels normally operate on a more limited set of routes, which are: the Triangle Route, the Mukilteo-Clinton Route, the Seattle-Bremerton Route and the San Juan Island Routes.

The Triangle Route

The Triangle Route consists of transits between terminals at Vashon, Southworth and Fauntleroy. Currently this route accounts for 56,200 gallons of diesel fuel usage per month.

Mukilteo-Clinton Route

The Mukilteo-Clinton Route accounts for 44,900 gallons of diesel fuel usage per month.



Seattle-Bremerton Route

The Seattle–Bremerton Route accounts for 88,000 gallons of diesel fuel usage per month.

The Island Routes

The Island Routes which consist of the Anacortes–Friday Harbor and Anacortes–Sydney BC accounts for 55,000 gallons and 71,000 gallons of diesel fuel usage per month.

4. Background, Objectives, and Scope

In March of 2010, the WSF received a report it had commissioned from the Glosten Associates of Seattle, WA. That report titled *LNG Use for Washington State Ferries* can be found in Appendix 1. The study had several purposes. First, it provided WSF with an introduction into the use of Liquefied Natural Gas (LNG) as a marine transportation fuel, and it specifically outlined the relative advantages and challenges for its use by WSF. Second, the study looked at the feasibility of using LNG fuel for propulsion in the construction of new vessels and the conversion of existing vessels to LNG fuel. The study covered issues of fuel storage, fuel safety, fueling, marine regulatory classification and commercial technology. Third, the study also presented a 'rough order of magnitude' (ROM) estimate for equipment costs, operating costs, and potential emissions reductions. The study concluded that although the capital cost of the LNG engines and tanks is high compared to conventional diesel equipment, fuel cost savings of $870,000 per year were estimated at today's prices. The study found that LNG propulsion engines could achieve important emissions reductions.

In July of 2011, WSF received a second study from the Glosten Associates titled *144-Car Ferry LNG Fuel Conversion Feasibility Study* (see Appendix 2 and 3). The primary purpose of the study was to review WSF's tentative exploration of powering a new 144-car ferry design with LNG fuel, with the potential to reduce operational costs and air emissions when compared to diesel fuel. The Glosten Associates were tasked with investigating the technical and economic feasibility of such a conversion and to identify regulatory requirements. The study concluded that the conversion was both technically feasible and cost effective, though many technical and regulatory challenges remained.

In January of 2012, the Washington State Legislature Joint Transportation Commission (JTC) received an independently contract study from the Cedar River Group of Seattle, regarding the use of LNG as a fuel for WSF vessels. The study was titled *Evaluating the Use of Liquefied Natural Gas in Washington State Ferries* (see Appendix 4). The study focused on the following areas: (1) assessment of WSF's work and studies on LNG use; (2) identification of the full range of issues that must be addressed to successfully implement LNG use; and (3) analysis of the cost, risk, timeline, and related implications of implementing LNG use for a retrofit of existing Issaquah class vessels, as well as incorporating LNG as a fuel into the new 144-car vessel design. The study was intended to address the Washington State Legislature's questions regarding the full potential cost of using LNG, which is less expensive and its price less volatile than the ultra low sulfur diesel (ULSD) currently used by WSF. The study recommended that the Washington State Legislature consider transitioning from diesel fuel to liquefied natural gas for WSF vessels, provided that such funding decisions were made in the context of an overall strategy that addressed operations, business, and vessel deployment and acquisition analysis.

In March of 2012 the Washington State Legislature appropriated funds for WSF to undertake the necessary safety and security planning processes and associated public outreach in pursuit of U.S. Coast Guard approval to retrofit and operate LNG fueled vessels.

5. Justification for and General Description of Changes

After several detailed studies WSF believes that it has sufficient information to expand its exploration of using LNG as a source of fuel for propulsion into the development of detailed safety and security operational planning. WSF believes that LNG provides an opportunity to significantly reduce fuel costs, and that it can also have a significant positive environmental effect. WSF burns more than 17 million gallons of fuel each year. Fuel is WSF's fastest growing operating expense. The fuel budget today is nearly 30 percent of the operating budget, or $67.3 million. That's $51.7 million more than it was 12 years ago. The fuel cost savings from converting to LNG could be approximately 40% to 50% over today's pricing of diesel. WSF's tentative retrofit plan envisions fuel savings of up to $195.5 million for the Issaquah class boats from the first potential conversion in 2015 to the retirement of the last converted vessel in 2042. Also, operating vessels with LNG could significantly reduce emissions, with nearly a 100 percent reduction in particulate matter and sulfur oxides, a 90 percent reduction in nitrous oxides and a 20 percent reduction in carbon dioxide.

The timing is also right because the use of LNG as a marine fuel for passenger ferries has been proven technically and has been operational for over a decade. Since 2000 the Norwegian government has allowed the construction and operation of LNG passenger vessels. There are currently more than 15 car and passenger ferries operating in Norway that are fueled by LNG. Additionally, both British Columbia Ferries and Staten Island Ferries are studying options to retrofit their vessels from diesel to LNG fuel, and the Quebec Ferries Company has contracted for three new LNG ferries. Also, there are LNG passenger vessels currently under construction or in design for service in Argentina, Uruguay, Finland, and Sweden.

6. Proposed Changes to Systems and Supporting Management Controls

6.1 The repowering of the Issaquah Class ferries to an LNG fueled vessel includes the removal of the existing GE 12V-228 diesel engines and installation of either a single fuel natural gas engine from Bergen or a dual fuel engine from Wartsila. The existing diesel fuel tanks would remain intact on the vessel and the ship's service generators (SSDG) would use the day tank which would provide approximately 30 days of fuel for the SSDG's. The LNG tanks would be located on the upper deck which is not used by passengers. There would be two tanks that are skid mounted located either side of the stack. The tanks are an integral assembly with a cold box and control system built in to control the bunkering process as well as the vaporization of the LNG to gas for use in the engines. The tanks are manufactured using the same technology used in the tank trucks certified to travel over the road. The capacity of each tank is 100 m^3 for a total capacity of 200 m^3 (48,000 gallons).

6.2 Changes to propulsion engines and associated piping to include as appropriate:

- 6.2.1 Remove existing main engines in No 1 and No 2 engine rooms
- 6.2.2 Install new natural gas main engines in No 1 and No 2 engine rooms
- 6.2.3 Install two (2) LNG storage tanks 100 m3 each on the uppermost deck
- 6.2.4 Install one LNG bunkering station on the No 1 end of the Car Deck
- 6.2.5 Install two natural gas supply lines: one to each engine room in double wall pipe
- 6.2.6 Install a wet main engine exhaust system for each engine
- 6.2.7 Install vent system and mast 30 feet above the deck

6.2.8 Gas detection System Integration: provided as a package from either engine supplier that meets IMO regulations

6.2.9 Control and monitoring instrumentation: provided as a package from either engine supplier

6.2.10 Electrical equipment: sensors for gas detection and ventilation system for vent system

6.2.11 Fire suppression systems: deluge system for each pilothouse and dry chemical system for bunkering station

6.3 Changes in safety, emergency response, environmental and security management to accommodate LNG operations.

6.3.1 Changes for LNG operations integration into WSF's existing Safety Management System (SMS): It is important to understand that WSF will incorporate LNG operations into its wide-ranging and integrated approach to safety, emergency response, environmental and security management for the entire Washington State Ferries system. The foundation for this approach is WSF's detailed and extensive Safety Management System (SMS). All policies and procedures regarding the use of LNG as fuel will be integrated into the SMS. The goal of WSF's SMS is to ensure that policies and procedures are clearly defined, that these documented policies and procedures meet or exceed regulatory requirements, and that the opportunity for continuous improvement is available to all WSF employees. WSF's intent with SMS is to provide "best practice" safety, emergency response, environmental and security guidelines for all WSF employees in a standardized approach, covering routine, critical, and emergent activities. SMS policies and procedures provide a structure within which managers and employees are expected to use sound judgment in the performance of their duties.

WSF's Safety Management System is evolutionary by design. This integrated management system approach has evolved in response to specific, independent and overlapping international, federal, state, local and agency rules, regulations and directives that apply to WSF operations.

The first of these standards, and foundation for the WSF Safety Management System, was the International Safety Management (ISM) Code for the Safe Operation of Ships and for Pollution Prevention. In January 1998 WSF launched it's on the international route; Anacortes, WA to Sidney, B.C. In April 1998, WSF was issued a Document of Compliance by the U.S. Flag State representative, indicating that the company met all the ISM Code requirements. In 2000, WSF made a commitment to the expansion of these best management practices across all WSF operations in order to have consistent policies and procedures throughout the system. Accordingly, fleet-wide implementation of all vessels, terminals, and the Eagle Harbor Repair Facility, occurred in April of 2001. With the enactment of the Maritime Transportation Security Act (MTSA), and the implementing regulations WSF developed a security plan in accordance with the U.S. Coast Guard-approved Alternative Security Program and integrated it into the SMS.

Through this evolution of function and integration of plans and complimentary management systems, the integrated SMS that exists today still retains the name and fundamental structure of the SMS that WSF put in place in 1998 to meet the ISM Code. The scope has expanded through the addition of elements to better address security, environmental protection and emergency response. The SMS has further expanded in applicability and scope to facilitate full organizational commitment as well as meet WSF's internal policy objective of providing best management practices across all programs and departments.

The written documentation of WSF's SMS is subdivided functionally. The first manual, Safety Management System Manual 1.1, is the definitive administrative document for the implementation of the WSF Safety Management System. This manual contains the descriptions of management system requirements for each of the programmatic components. It also contains related WSF overarching policy and organizational documents. Manual 1.2 contains the policies and procedures describing WSF's compliance with specific programs. Manuals 2 through 12 are department-specific manuals. These manuals contain department-specific policies and procedures directly applicable to those employees working at terminals, on vessels, in the warehouse, at the Eagle Harbor Repair Facility, and at the corporate office. Manuals 13 through 39 are route- and vessel-specific manuals, which contain information unique to those routes or vessels.

In addition to a well documented SMS, WSF has a robust management structure to oversee SMS development, integration and maintenance. WSF's executive management team forms a SMS Policy Committee (SPC). Furthermore, to ensure coordination across departments the SMS Coordination Team (SCT) brings together key representatives from each department.
The Safety Systems Manager works with the SPC and SCT to effectively address safety, emergency management, environmental protection, and security issues and initiatives that cross departments, without compromising traditional line responsibilities and accountabilities.

Prior to the commencement of LNG fuel transfers WSF will define in policy and operational documentation areas at each WSF terminal were LNG fuel trucks and associated equipment for the transfer to a vessel will be allowed to operate. These areas will constitute the designation of a marine transfer area for LNG as required by 33CFR127.005. These areas will be permanently marked and appropriate safety and security measures will be incorporated into the approved transfer procedures.

In addition to detailed transfer procedures WSF will incorporate the necessary policy and procedures into our extensive Safety Management System Operations Manual and Emergency Manual: Procedures for examination.

6.3.2 Changes to WSF's SMS to address safety and security training requirements for LNG operations:

6.3.2.1 WSF will modify our existing SMS procedures to outline the duties of the Persons in charge (PIC) of shore-side LNG transfer operations. Additionally WSF will ensure that no person will serve as a PIC unless they have at least 48 hours of LNG transfer experience. The training and knowledge will most like be obtained with the assistance of the supplier of LNG. WSF will ensure that PICs are certified in writing and copies of each current certification available for inspection for each vessel receiving LNG. WSF will ensure that the designated PIC will have training in the following subjects: General hazards of LNG; procedures in the WSF specific

LNG Operations Manual and WSF LNG Emergency Manual; an overview of LNG vessel design and cargo transfer operations; LNG release response procedures, LNG security transfer procedures; and first aid procedures for: frostbite, burns, cardio-pulmonary resuscitation; and transporting injured personnel. This training will be conducted at least once every five years.

6.3.2.2 WSF will ensure that all full-time employees that serve in a fire fighting team aboard a LNG fuel vessel will have training in the following subjects: LNG firefighting procedures; LNG properties and hazards; overview of WSF LNG Operations Manual and WSF Emergency Manual procedures; LNG transfer security procedures; LNG release response procedures; first aid procedures for: frostbite, burns, cardio-pulmonary resuscitation, and transporting injured personnel. This training will be conducted at least once every five years.

6.3.3 Changes to WSF's SMS to address LNG fuel transfer operations:

6.3.3.1 WSF will designate in writing the dimension of each marine transfer area where LNG will be transferred between tank trucks and vessels.

6.3.3.2 WSF will develop WSF specific LNG Operations Manual and LNG Emergency Manuals.

6.3.3.3 WSF will develop Preliminary Transfer Inspection procedures. These procedure will direct PICs to: inspect the transfer piping and equipment to be used during the transfer and replace any worn or inoperable parts; note the pressure, temperature, and volume to ensure they are safe for transfer; review and agree with the PIC cargo transfer at the tank truck the sequence of transfer operations, the transfer rate, the duties, location, and watches of each person assigned for transfer operations. It will also direct the PIC to ensure that transfer connections allow the vessel to move to the limits of its moorings without placing strain on the loading hose; ensure that each part of the transfer system is aligned to allow the flow of LNG to the desired location; ensure that temporary warning signs that warn that LNG is being transferred, are displayed; eliminate all ignition sources in the marine transfer area for LNG; ensure that personnel are on duty in accordance with the LNG Operations Manual. The manual will also outline test procedures to follow that ensure: the sensing and alarm systems, the emergency shutdown system and the communication systems are operable before the transfer.

6.3.3.4 WSF will develop WSF specific Declaration of Inspection forms that will contain: the name of the vessel and the waterfront facility handling LNG; the date and time that transfer operations begin; the signature of the PIC

6.3.3.5 The WSF LNG Operations Manual will ensure that there are procedures to address the following: procedures to ensure that the marine transfer area for LNG is under the supervision of a person in charge at all times; that transferring fuel or oily waste are not permitted during an LNG transfers; that no vessels are moored outboard of any LNG vessel without the permission of the COTP; that PIC be in continuous communication with the PIC from the truck; and that transfer operations are discontinued if there are electrical storms or uncontrolled fires adjacent to the marine transfer area for LNG

6.3.3.6 The WSF LNG Operations Manual will have procedures to ensure that access to the marine transfer area for LNG is limited to: personnel who work for WSF; LNG delivery and service personnel in the course of their business; Coast Guard personnel; and other persons authorized by WSF management. The procedure will ensure that no person is allowed into the marine transfer area for LNG unless that person is identified by a WSF identification card or other identification card displaying his or her photograph, or is an escorted visitor displaying an identifying badge.

6.3.3.7 The WSF LNG Operations Manual will also have procedures to ensure that security rounds of the marine transfer area for LNG are conducted once every hour, or that a manned television monitoring system is used, to detect: unauthorized personnel; fires; and LNG releases.

6.3.4 Changes to WSF's SMS to address ignition source control and firefighting shore side:

6.3.4.1 WSF will have procedures to ensure that proper firefighting equipment is available and incorporated into procedures and training.

6.3.4.2 WSF will develop procedures to ensure that there is access to the WSF facilities by firefighting personnel, fire trucks, or other emergency personnel is not impeded.

6.3.4.3 WSF will supply a sufficient number of fire extinguishers approved by an independent laboratory fighting small, localized fires are in place throughout the facility and maintained in a ready condition.

6.3.4.4 WSF will ensure that the location of each hydrant, standpipe, hose station, fire extinguisher, and fire alarm box is conspicuously marked and readily accessible.

6.3.4.5 WSF will ensure that temporary signs indicating that smoking is prohibited are posted in areas where smoking is not permitted. WSF will ensure that welding or hot work is prohibited during transfer of LNG.

6.3.4.6 WSF will purchase communications systems for the marine transfer area for LNG that provides a ship-to-shore communications. The system will allow voice communication between the PIC for the ferry and the PIC in charge of shore side transfer operations, and personnel in the control room.

6.3.4.7 The vessels will be equipped with fixed sensors must have audio and visual alarms in the control room and audio alarms nearby. The fixed sensors will continuously monitor for LNG vapors, flame, and heat.

6.3.4.8 WSF will purchase and incorporate in to procedures portable gas detectors. WSF will ensure that at least two portable gas detectors capable of measuring 0-100% of the lower flammable limit of methane will be available at each transfer of LNG.

7 Overview of Operational Scenarios

7.1 Bunkering Operations (see Appendix 5 for full detail)

7.1.2 The bunkering operation will occur during night tie-up as it is done today for this class of ships. The vessel will be secure with the master in the No 1 pilothouse. The master will inform the port that the bunkering operation will be taking place when the tanker truck arrives.

7.1.3 The vessel will have prepared the vessel for the arrival of the tanker truck. A pump trailer is used to transfer the LNG from the tanker truck to the LNG tanks on deck, a lift of approximately 26 feet. The trailer is equipped with two pumps and two 150 ft^3 bottles of compressed nitrogen for purging the lines. The trailer will mimic the connections at the bunkering station with the nitrogen, supply and vapor return connections already made up to the bunkering station, but all manual and automatic valves are secured. The trailer is powered by a power connection located on the bulwark. The trailer and hoses are all bonded to the vessel and the transfer span is bonded to the ship.

7.1.4 When the tanker truck arrives it backs down the transfer span within 25 feet of the end of the span. The hose troughs are laid out for the truck. The truck is bonded to the transfer span and the hoses for the transfer are laid out into the troughs and connected to the tanker and the trailer. The tanker will increase the pressure in its tank to get it within ten psi of the vessel's storage tanks. Once the pressures are within ten psi and the connections are made, the pre-bunkering checklist is gone through with the tank truck operator and the Chief Engineer and signed. Once signed, the vapor return lines are opened to equalize the pressure in the supply and receiving tanks and a small amount of LNG is released into the supply line to purge the air from the line. The LNG is then slowly released to the trailer where it is pumped up to the storage tanks. The process continues until the LNG is transferred. The tanker truck will increase the pressure in tank and push the remaining LNG into the vessel's storage tank.

7.1.5 When the LNG is purged from the bunkering lines, the vapor return line is closed and the line is purged with nitrogen from the transfer trailer through the bunkering line and up to the vent mast. The automatic and manual valves are secured and a checklist is completed. The master will notify the port that the bunkering procedure is complete.

7.2 Unintended release of LNG

7.2.1 At a storage tank on deck would be through a vent line to the vent mast from the tank due to an over pressurization or valve failure. The leak would be alarmed and the system, depending on the cause of the release, would be isolated or corrected.

7.2.2 Any natural gas in the engine room would cause an alarm and the shut-down of the engine in that space. The system is an intrinsically safe system so any presence of natural gas would be a casualty. There is no LNG in the engine room only natural gas.

7.2.3 At the bunkering station any leak or inadvertent spillage would be caught in troughs that would contain the spill and allow the LNG to transit to the water. The personnel on site would stop the bunkering process until the cause of the leak was determined and a repair completed.

7.2.4 Dry dock or extended maintenance availability

7.2.5 Hot-work – The tanks are manufactured as units and will be maintained by the manufacturer. All other gas and bunkering piping systems can be purged and inert with nitrogen.

7.2.6 Boil-off – the tanks can store the LNG for up to 90 days without any significant boil-off.

7.2.7 De-bunkering – the tanks could be de-bunkered by differential pressure.

8. Proposed Scope for Safety and Security Risk Assessment

WSF proposes to conduct a thorough safety and security assessment before any final decisions are made regarding the conversion of Issaquah class vessels to LNG. The assessment will use a methodology that meets generally accepted risk-based decision-making industry standards and will be as objective and transparent as possible. The assessment will outline conditions that could result in a release of LNG be it accidental (e.g., collisions, groundings, equipment failure, etc.) or intentional (e.g., terrorist act, sabotage, etc). The goal of the safety and security assessment is to discern and understand the individual risks in terms of threats, vulnerabilities, and consequences, so that appropriate risk management strategies can be developed. The assessment will identify key assumptions and will provide some sensitivity analysis to determine how much the outcome of the risk assessment is impacted by a slight change in any of the key assumptions. The safety and security assessment will include the following:

8.1 The assessment with provide a characterization of the routes where LNG fueled ferries may operate. The assessment will catalogue and describe all WSF ferry routes and may sub-divide the routes into segments based on a logical methodology. The assessment will consult local waterways users.

8.2 The assessment will consider the density and character of marine traffic along each segment of the waterway as outlined in 33 CFR 127.007. The assessment will examine and identify commercial, military, and recreational vessel use.

8.3 The assessment will use the "Zones of Concern" listed in enclosure (9) of *NAVIGATION AND VESSEL INSPECTION CIRCULAR (NVIC) NO 01-2011* or other zone sizes acceptable to the Vessel and Facility Operating Standards Division (Commandant (CG-5222)). The assessment will use modeling studies for the length of each transit to determine the main areas of concern along the waterway. The assessment will include graphics that depict the outer perimeter of the zones along the entire vessel transit route in order to assess what port and community features fall within them.

8.4 The assessment will indentify critical infrastructure and key assets along the routes and compare this information with those listed in the Area Maritime Security Plan.

8.5 The assessment will examine the waterfront community demographics and important structures including industrial, commercial, residential districts; city centers; military installations; schools; hospitals; cultural centers; etc, along the entire LNG fueled ferries' transit routes.

8.6 The assessment will examine population density along the routes and classify them into two categories. The categories are "High density populations" which will designate areas with 9,000 persons per square mile or greater and "Medium density populations" which will designate areas with 1,000 to 9,000 persons per square mile.

8.7 The assessment will evaluate the risks of accidental releases of LNG. The assessment will include incidents that may lead to an accidental release and identified the likelihood and consequences of those events.

8.8 The assessment will cover security risks for an intentional release of LNG. The assessment will include three separate sub-assessments: threat, vulnerability, and consequence. The assessment for security will examine the probability of an event of threat and vulnerability. The assessment will evaluate the ways in which a particular attack may be carried out. The assessment will address specific attack scenarios to include sabotage, projectiles, aerial, and surface threats. The assessment will identify areas in the port such as manmade structures, tributaries and land masses along the transit waterway from which an attack could be launched.

The assessment will include a vulnerability analysis that will identify the exposures that might be exploited to ensure the success of an attempted terrorist attack. The assessment will consider two types of vulnerabilities, asset and system. The asset vulnerabilities are physical properties of the target that may influence the likelihood of success of a terrorist attack. The system vulnerabilities are the ability of the terrorist to successfully launch an attack. The assessment will then graphically depict where zones of concern intersect with population areas, critical infrastructure and key assets, critical waterways, and commercial, industrial, or environmentally sensitive areas in and adjacent to the transit route. This will identify those areas where an intentional release of LNG would have the most significant consequences.

9. Proposed Risk Management Plan

Based on the findings of the safety and security assessment, WSF will develop a risk management plan that identifies the best ways to prevent an identified attack or accident from occurring. The plan will also develop measures to mitigate the consequences should a breach of the LNG fueled ferry occur. The plan will identify how these measures may be applied to comport with the changes in the Maritime Security (MARSEC) Levels and the regulation found in 33 Code of Federal Regulation Subchapter H. The plan will integrate local fire fighting, security and emergency response resources. The plan will comport with local fire codes, and regulations. The plan will WSF will identify possible risk management strategies for areas of risk identified by the safety and security risk assessments and WSF in consultation with the U.S. Coast Guard Captain of the Port Puget Sound will determine which risk management strategies are appropriate.

10. LNG Operations Manual

WSF will write and submit for review and approval an operations manual to the U.S. Coast Guard Captain of the Port, Puget Sound. The contents of the operation manual shall contain at a minimum and as appropriate the information outlined in 33 CFR 127.305 and any other information required by U.S. Coast Guard Captain of the Port, Puget Sound.

11. Review of the Safety and Security Assessment and the Risk Mitigation Plan

WSF proposes that there be a review of the Safety and Security Assessment, Risk Mitigation Plan and LNG Operations Manual by a knowledgeable peer review group. That peer review group would be selected by the U.S. Coast Guard Captain of the Port, Puget Sound. The appointees to this peer review group could be drawn from groups that represent large segments of the maritime community in the Puget Sound area. Appointees could also be selected to represent specific segments of the maritime community, i.e. fire departments, law enforcement, shipping, waterways users, etc. This group would advise the U.S. Coast Guard Captain of the Port, Puget Sound in making a final determination on the proposed operations.

12. Community Outreach Plan

WSF understands that it is important to provide the media and the general public with accurate and objective information about LNG safety. WSF knows the value of early proactive public engagement, and that WSF and the U.S. Coast Guard Captain of the Port, Puget Sound will be the primary representatives to the community. Therefore, in coordination with the U.S. Coast Guard Captain of the Port, Puget Sound, WSF will develop a comprehensive community outreach plan that will seek to inform and educate stakeholders.

LNG Use for Washington State Ferries

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Executive Summary

LNG use as a marine fuel is both practical and cost effective and has been used in Norway for fueling ferries for over a decade. A high level discussion of adapting the WSF 144 vehicle ferry design for use with LNG fuel indicates that the volume exists to add LNG tanks of adequate size while still allowing weekly bunkering. Although the capital cost of the LNG engines and tanks is high compared to conventional diesel equipment, fuel cost savings of $870,000 per year are estimated at today's prices. For pure gas propulsion engines NO_x emissions reductions will be at least 90% and PM and SO_x emissions will be reduced nearly 100%. CO_2 emissions reductions from pure gas propulsion engines will be approximately 20%.

Introduction

This paper is an introduction to the use of Liquefied Natural Gas (LNG) as a marine transportation fuel, and specifically the advantages, and challenges for its use by Washington State Ferries (WSF). Both new construction and conversion are considered. Issues of storage, safety, fueling, marine regulatory classification and commercial technology are discussed for context and background. Finally a high level look at adding LNG capability to a WSF vessel are discussed including 'rough order of magnitude' (ROM) equipment costs, operating costs, and emissions reductions.

The EPA Clean Diesel program prescribes a path for the stepwise reduction of emissions from diesel engines. Nitrogen Oxides (NO_x), Sulfur Oxides (SO_x), and Particulate Matter (PM) emissions are regulated nationally by the EPA, and regionally by other agencies at the state and local level. For Category 2 marine engines, which encompasses engines sizes used by WSF, Tier 2 emissions levels are now binding. Tier 3 levels will be in effect as early as 2013 and will be addressed with on-engine technology to meet regulations. To comply with Tier 4 regulations, which are effective as soon as 2014, engine manufacturers will likely require off-engine (exhaust after treatment) technology. Reducing NO_x with after-treatment requires the use of Selective Catalytic Reduction (SCR). This technology requires continuous consumption of aqueous urea (typically 5-10% of diesel fuel consumption) and will likely represent a significant operating expenditure for SCR equipped vessels.

Using LNG as a marine fuel could allow WSF to achieve similar NO_x, SO_x, and PM emissions and 20% lower CO_2 emissions when compared to Tier 4 diesels, but without the use of costly after treatment. If the natural gas is produced from renewable sources, such as biomass, the carbon footprint can be reduced by up to 80%.

Using natural gas as a transportation fuel presents an opportunity to improve US energy security, as compared with petroleum, which dominates the US transportation sector. Natural gas is largely produced domestically, with imports accounting for only 10 percent of gas used. Use of natural gas in transportation has been steadily increasing for the last decade with LNG and CNG (compressed natural gas) being the dominant forms used for this purpose. LNG is created in a process called liquefaction, which in addition to liquefying the fuel it purifies it to at least 95% methane. LNG is the most energy dense form of natural gas.

On an energy basis natural gas is much cheaper than oil. Oil at today's price of $80 per barrel has a cost per energy of $13.80 per mmBTU. As a comparison natural gas costs under $6 per mmBTU. Historically this price gap is tending to widen and favors natural gas. The energy and transportation costs associated with production and delivery of LNG add cost, but LNG is still significantly cheaper than diesel.

Background

LNG is a cryogenic fuel that is maintained at approximately -260°F at atmospheric pressure. The advantage of cooling and liquefying the fuel is that the volume is decreased approximately 600 times as compared to the gas. This improves the energy density significantly for LNG. As a result when compared to diesel fuel LNG has about 2/3 as much energy on a volume basis and almost 90% as much energy on a weight basis. Unfortunately, storing cryogenic (very cold) fuels requires special insulated tanks that significantly erode much of the volume and weight advantages of LNG.

Storage

LNG is typically stored in highly insulated, spherical, or cylindrical tanks at low pressures, (15 - 75 psig). Fitting these tanks on a ship or in a vehicle is quite feasible but does not compare favorably to diesel. In practice it should be expected that the volume required to store LNG will be about 3-4 more than the comparable volume of diesel.

Safety

LNG as a liquid is not flammable or explosive. As with any gas it has a flammability range. This range for LNG gas is between 5 and 15 percent when mixed with air. An explosion can only occur when the gas is in an enclosed space with air, the mixture is between 5 and 15 percent, and an ignition source is present. As with any flammable substance, proper design, regulations, and personnel training are needed to maintain a safe environment.

Compressed Natural Gas

LNG should not to be confused with CNG (compressed natural gas). CNG is another form of natural gas storage that is used widely in transportation. Typically CNG is stored in cylindrical or spherical tanks at pressures of 3000 to 4000 psig. Even at these high pressures, the energy content is less than half that of LNG. The marine classification rules, discussed more below, do not allow below deck storage of CNG. This limitation, along with a relatively lower energy density makes CNG a less desirable choice for fueling ferries.

LNG as a Transportation Fuel

LNG is used today as a transportation fuel but the market is still small compared to most other alternative transportation fuels. Clean Energy Fuels, a large national supplier of LNG, distributes 3.5 million gallons of LNG per month for vehicle transportation. It is typically transported by truck from liquefaction facilities to the fueling stations. The transportation of LNG is a major contributor to the cost of the fuel, so reducing the transportation distance from the liquefaction facility to the point of use results in a tangible cost reduction.

LNG is in limited use in Washington State today, but if a large enough market existed in the Puget Sound area, the supplier would build a liquefaction plant. Currently two liquefaction facilities exist on the Washington/Oregon border and another on the Canadian side of the Washington/Canada border. One LNG fueled ferry similar in size to the new 144 vehicle ferry would likely consume enough LNG to justify a Puget Sound liquefaction plant.

LNG Buses

A number of large LNG bus fleets are in operation in the US today. The city of Phoenix PTD (Public Transit Department) operates a fleet of 351 LNG buses, representing 71 percent of the city's fleet. Dallas Area Rapid Transit (DART) has been operating a large fleet of heavy duty buses fueled by LNG since 1998 and today the fleet has grown to 181 LNG buses. Tempe, Arizona operates a fleet of over 100 LNG buses.

LNG in Ports

Today in the United States ports, about 500 trucks are operating on LNG as a fuel. Another 500 trucks will be deployed in early 2010. This growth rate will likely continue as the differential costs between LNG and diesel continues to widen, and as pressure on ports from adjacent population centers push for tighter emissions controls.

LNG as a Marine Fuel

LNG has been used as a marine fuel for decades starting with large carriers fueled from the boil off gases in their storage tanks. Modern LNG carriers carry liquefaction plants for boil off gas that allow them to use more efficient slow speed diesel engines. However, a number of newer LNG carriers on order or in operation today carry large dual fuel generators, affording them the flexibility to use either LNG or diesel.

LNG Ferries

Norway, which has the largest fleet of LNG fueled ships in the world, has been operating a number of ferries since 2000. There are at least 6 car ferries fueled by LNG in operation today, three more to be delivered in 2010, and by 2011 the fleet is expected to be 11 ferries. High national emissions taxes on NO_x and others pollutants have been the primary driver in the adoption of LNG fueled ferries.

Other LNG Vessels

In addition to ferries, there are other vessels that are in operation in Norway today that are primarily or solely fueled by LNG.

- Two platform supply vessels (PSV), delivered in 2003
- Small coastal LNG carrier, combination gas and diesel, delivered in 2004

- Three coast guard vessels operating on a combination of gas and diesel, 2008

LNG Bunkering

Fueling ferries with LNG will require a number of considerations for WSF and an understanding of the similarities and the differences from handling diesel. Since LNG is a liquid it can be pumped through hoses and attached to fueling manifolds on the vessel. Fuel transfers must be handled with care by trained personnel. Spills are avoided through proper design and training, but should a spill occur it must be contained. Fuel can be bunkered directly from tank truck or from a dedicated bunkering station at the dock.

Bunkering by Tank Truck

Bunkering by tank truck is commonplace for LNG vessels in Norway. The PSV's are normally bunkered by truck, since the remote quays are far from liquefaction facilities. Tank trucks today carry about 10,000 gallons per truck so this approach is most practical for smaller loads. Dock space, transportation distance from LNG storage facility, available bunkering time and other issues can make this fueling method logistically challenging if more than a few trucks are required. Figure A1 and A2 in the appendix show the bunkering of a Norwegian PSV.

Bunkering from On Shore Storage Tanks

In some cases, it may be most practical to have a large storage capacity on shore, connected by pipe to a dockside bunker station. This approach allows for a larger quantity of fuel to be transferred in a shorter period of time, making a shorter bunkering cycle more practical. It also relieves the crew from much of the logistical issues of switching tank trucks, or directing traffic.

At least some ferries in Norway are using dedicated dockside bunkering facilities. Typically the LNG tanks are located several hundred yards inland from the dock, allowing them to be filled independently from the ferries normal bunkering schedule. Underground pipes carry the fuel from the shore side tanks to an elevated hose station on the dock, allowing the ferry a convenient means of getting the fuel. A streamlined operation is critical since the bunkering cycles are as short as three days.

Other issues

Since the LNG needs to be maintained at a very low temperature, it is critical that at least some liquid remain in the tanks at all normal operating times. If an LNG tank is fully emptied, for example for maintenance or repair work, the tank will immediately begin to warm to ambient temperature. When the tank is refilled, or filled for the first time, a cooling down period is required which can take several days. This also affects the tank sizing and fuel system design since emptying the tanks completely would be an emergency or a scheduled event only.

Classification and Regulation

Rules for classifying LNG fueled vessels other than LNG carriers are available from Det Norske Veritas (DNV) and Lloyds Register. Other classification societies may be developing rules as well in recognition of the growing marine market. These rules are largely based on well established safe design practices of the International Maritime Organization (IMO) International Gas Carrier (IGC) Code. There are likely to be differences between society rules until unification effort are made by International Association of Classification Societies (IACS) or IMO. Currently American Bureau of Shipping (ABS) does not have rules applicable to LNG fueled passenger vessels. Since DNV has the greatest amount of experience in classing ferries, it would be a good choice for WSF.

Some of the key features of the DNV rules are presented below. DNV has more experience than any other classification society in classifying ferries since they were the first to create these rules and have applied them to a number of vessels and vessel types.

Gas Fuel Storage

Various requirements for LNG storage tanks and gas piping are described in the rules. Placement of LNG tanks below the main deck is essential for the efficient design of a ferry. Class rules allow placement of LNG below the main deck but various safety requirements are imposed that must be considered at the concept level by the designer.

1. **Distance from side shell:** The lesser of 1/5 of the beam or 11m (36 feet)
2. **Distance from bottom shell:** The lesser of 1/15 the beam or 2m (6.6 ft)
3. **Tank type:** Must be independent IMO 'Type C' (pressurized) tanks
4. **Liquid only:** Only gas in a liquid state can be stored below the main deck level
5. **Maximum working pressure:** 10 bar (145 psig) working pressure for tanks
6. **Secondary barrier:** Storage tank and associated valves and piping must be located in a space designed to act as a 'secondary barrier'. Typically this is addressed by a double walled tank design and a 'tank room' connected to the outer wall. The 'tank room' is integral to the tank and fulfills the 'secondary barrier' requirement.

Safety Design Philosophies

Two safety design philosophies are described in the DNV rules. Both are considered acceptable but they are fundamentally different in their approach.

1. **Inherently Safe:** The arrangements in the machinery spaces are such that the spaces are considered 'gas safe' under all conditions, normal as well as abnormal. All gas piping is enclosed in ducts or double-walled pipes in the engine room. The annular space is either filled with an inert gas at a higher pressure than the center pipe, or it is ventilated to 30 air changes per hour with gas detection at the outlet.
2. **Emergency Shutdown (ESD):** Spaces with gas piping are considered non-hazardous under normal conditions, but under certain abnormal conditions may have the potential to become gas hazardous. In the event of abnormal conditions involving gas hazards, emergency shutdown of non-safe equipment (ignition sources) and machinery shall occur automatically. Additionally, equipment in use during these conditions shall be of explosion-proof design. Therefore the ESD philosophy requires a second engine room to maintain operations if one engine room should need to be shut down.

The ferries operating in Norway today are designed with the ESD philosophy. This is a fundamentally less conservative approach and may meet with greater resistance from the USCG. It requires inherently safe and/or explosion proof equipment in the engine room, which adds expense, as well as complicating design and arrangements.

The Inherently Safe method completely isolates the fuel from any ignition sources, and therefore does not require normal engine room equipment to be explosion proof or inherently safe. It does require double piping of the fuel line right up to the engine, however. Engine manufacturers must therefore provide appropriate on-engine connections.

Both approaches have extensive ventilation and gas monitoring requirements.

Independent Fuel Source

Class rules require an independent fuel supply. If LNG is the only propulsion fuel used on board then the fuel system must be divided between two or more tanks of approximately equal size, and the tanks located in separate compartments. The ferries operating in Norway today all operate on gas only, and have multiple independent cryogenic tanks.

This requirement can also be met through the use of Dual Fuel (DF) engines that run on both diesel and natural gas. The DF engine must be capable of switching between fuels reliably without shutting down. If DF engines are used, diesel fuel must be carried, as a minimum to act as a pilot fuel, since DF engines are not spark ignited. The diesel fuel will suffice as a secondary fuel source and therefore a second cryogenic gas storage tank is not required. The PSV's in Norway use DF engines and only carry a single cryogenic tank.

Another way this requirement can be satisfying is by installing both diesel engines and gas engines with the capability to transmit power to the propeller. Obviously a completely independent diesel fuel system must be installed. This approach has been used in several vessels in Norway.

From a design arrangement perspective, fitting the LNG tank(s) is one of the primary challenges and often a starting point of design. Sometimes, it is not possible to fit a sufficient quantity of fuel into a single tank and therefore two or more tanks may ultimately be required anyway.

USCG

Since no LNG fueled passenger or non IGC commercial vessels have yet been built in the United States (other than small retrofit pilot projects), the USCG does not have an established path for review. Therefore early engagement with the USCG to discuss an approach to gaining their approval of an LNG ferry is essential for WSF. Many questions remain not the least of which is finding a reasonable approach to crew training and licensing.

Training and Licensing

No USCG training or licensing requirements are known.

The IMO has interim Guidelines BLG (Bulk Liquids and Gas) 13/6 under development. These guidelines address gas related training in three categories:

A. Basic training for the basic safety of the crew (8.2.1.1)
B. Supplementary training for the deck officers (8.2.1.2); and
C. Supplementary training for the engineering officers (8.2.1.3)

Further information on how this training would be implemented, enforced, or whether USCG would require similar training for domestic passenger vessels is not known.

As with many types of marine equipment, special training can often be provided by the equipment vendor as a condition of sale.

Commercial Marine LNG Prime Movers

Very few options are available for proven marinized LNG prime movers. Additionally, the options will vary depending on the propulsion approach. Rolls Royce and Wartsila both have options for direct drive engines, or propulsion generators either currently on the market or coming to the market soon.

Rolls Royce (Bergen)

Over the last several decades Bergen has invested significant research and development efforts into gas combustion technology with the first commercial gas engine available in 1991. The first marine application was in 2005 and today at least 5 ferries are operating with Bergen gas propulsion generator sets.

Bergen engines are 'lean burn' spark ignited (SI) engines. A rich gas-air mixture in a pre-combustion chamber is ignited and forms a strong ignition source for the very lean mixture in the cylinder. In the lean burn engines more air is in the cylinder than is needed for complete combustion. This reduces peak temperatures and therefore lowers NO_x emissions. The electronic control system constantly monitors and optimizes operating parameters to maintain power and emissions across the operating range. The engines produce very low NO_x, even at low load. The Bergen gas offerings are outlined below.

- Gas B Engines:
    - Classed for direct drive and electric drive
    - 720-750 rpm
    - Power range from 6,760 – 9,380 hp
- Gas C Engines:
    - Classed for direct drive and electric drive starting in 2011
    - 900-1000 rpm
    - Power range from 1,960 – 3,260 hp

Wartsila

Wartsila has focused entirely on DF engines for the marine market and has produced and sold hundreds of DF engines for LNG carriers over the last decade. In recent years Wartsila has increasingly focused on the smaller power ranges and also on offering the DF engines for direct drive.

The Wartsila DF engine can operate normally on either diesel fuel or natural gas. When operating on gas the engine uses a small amount of diesel (~1%) as a pilot fuel to initiate combustion. The Wartsila DF engine, like the Bergen gas, operates on the 'lean burn' principle for low NO_x operation. Therefore the emissions performance, while not as clean as pure gas, is excellent and offers the added advantage of switching to diesel on the fly if desired. Therefore the 'range anxiety' that could be associated with pure gas for certain applications is eliminated. The DF engines are electronically governed, and offer a high efficiency. The Wartsila DF offerings are outlined below:

- 20DF
    - Classed for electric drive.

   - Direct drive coming soon
   - Power range from 1,400-2,100 hp
- 34DF
   - Classed for electric drive
   - Power range from 3,500 – 9,300 hp
- 50DF
   - Classed for direct drive and electric drive
   - Power range from 7,640-23,000 hp

Pure Gas vs. DF

Pure gas engines offer superior emissions performance and response time to DF engines. Classification rules require vessels operating with gas fuel alone to carry two independent gas tanks and fuel systems to maintain redundancy. The use of DF engines avoids the use of redundant cryogenic tanks, but DF engines require the use of diesel fuel for normal operation so a secondary fuel system must be installed regardless.

For a WSF ferry, DF is not necessarily an obvious advantage since proximity to LNG supply in Puget Sound is not an issue. Also, fitting a single large LNG tank into a ferry may not be possible, and the designer may therefore be driven to a dual tank arrangement anyway. At present neither Wartsila nor Rolls Royce have direct drive options in the power ranges of WSF vessels although both companies claim they are coming in the next several years.

Other Manufacturers

For the LNG carrier market MAN has been developing DF technology but commercial offerings are not advertised. Many diesel engine manufacturers have gas engine offerings but are not pursuing the marine propulsion market, since it is presently so small. Therefore marinized offerings are very limited at this time.

Application to Washington State Ferries

Adding an LNG vessel to the WSF fleet offers potential emissions as well as operational cost benefits. The two possibilities are to construct a new vessel or to convert an existing vessel within the fleet.

Conversion of an existing ferry to LNG technology is possible, however would likely not be cost effective. Issues for consideration of converting an existing vessel are listed below:

- Identification of the appropriate vessel
   - Vessel needs to be of an appropriate size to allow practical storage of below deck LNG tanks.
   - Operational profile (power level, run time, etc) need to be considered to appropriately size the tanks.
   - Vessel needs to have an appropriate life expectancy to justify an investment in an LNG conversion.

- Getting an existing vessel classed may present significant challenges (current vessels are USCG inspected only but USCG may well require that the vessel be classed by an experienced society such as DNV to mitigate risk).

- Installing large LNG tanks below the main deck is likely to be a technical challenge, and very costly within an existing superstructure.
- Removal of a significant amount of under deck machinery and equipment will be required as well as redesign of under deck engineering spaces.
- Superstructure will require modifications for gas venting and ventilation arrangements.

Adapting the 144 vehicle design for LNG

New construction of an LNG vessel for WSF is more straightforward than converting an existing vessel since locating the tanks, engines, ventilation, and fueling system can be done before construction. However since WSF already has an existing design for a 144 vehicle ferry, the most economical way to bring a new LNG fueled vessel into the fleet would be to adapt the existing design if possible. Classing the design with DNV or Lloyds is an issue that must be considered at the concept level. The following section considers adapting the newly designed 144 vehicle ferry to LNG fuel.

For simplicity the following assumption have been made:

- The propulsion system will operate on pure LNG (not Dual Fuel)
- Engines: 2 – Bergen C9PG Gas propulsion engines, 3200 bhp each
- 2 LNG storage tanks
- All other associated gas auxiliary equipment and piping are assumed to fit within the space available for diesel equipment and do not require special consideration.
- Annual consumption of diesel fuel based on *Issaquah* class vessel.
- Minimum 1 week LNG bunkering cycle.

LNG Tank Sizing

The size of the required LNG tanks is governed by the fuel consumption. For simplicity the fuel consumption is assumed to be roughly equivalent to the *Issaquah* class, or 800,000 gallons per year. This translates to a weekly diesel consumption rate of approximately 15,000 gallons and an LNG volume of 28,000 gallons (on an energy equivalent basis). Therefore with margin, the minimum LNG volume is approximately 30,000 gallons.

Arrangements

The molded beam of the 144 vehicle ferry design at the waterline is approximately 74 feet. This restricts the tank location to approximately 15 feet from the side shell and 5 feet from the bottom shell. With a few iterations it was determined that the LNG volume could be fit into the hull with two tanks, arranged amidships just below the engineering spaces (Figures A3 – A5 in Appendix). The engineering spaces will need to be rearranged but the basic hull form will not have to change. The medium speed engines are assumed to be similar in size to the engines currently specified and therefore engine arrangements were not considered further.

Auxiliary Power

Providing auxiliary power to the ferry requires special consideration. The peak auxiliary power requirements for the 144 vehicle design are approximately 350kW, provided by a primary and standby diesel generator set. Currently there are no gas generator sets available on the market, in this size range that are designed for inherently safe installation (double walled piping to the engine). Therefore, the most straightforward solution to this is to assume diesel generator sets would be installed.

However, there are several disadvantages to installing diesel generator sets on a vessel designed for pure LNG. First is that it requires that the vessel have a complete diesel system installed on board (storage tanks, bunker lines, fuel delivery lines, pumps, filters, etc). Installing and maintaining the diesel fuel system is a tangible cost to WSF. Second, the diesel generator sets will negatively offset the emissions reductions that are a primary goal of installing LNG in the first place. If the generator sets were Tier 4, the emissions would be very low, but meeting Tier 4 will require after treatment technology. This means additional expenses incurred for urea, and systems for urea storage and delivery.

One possible solution is to equip the propulsion engines with power take off (PTO) capability so that the main engines also provide auxiliary power. Standard PTO solutions require the main engines to operate at synchronous speeds to provide power to the alternator but the 144 vehicle ferry is intended for variable speed operation. However it is technically feasible to install PTO alternators that can take variable speed input and produce 60 Hz power output through the use of solid state frequency converters. Although the technical issues of this approach are outside the scope of this discussion, it would allow the vessel to operate with lower emissions and fewer subsystems to install and maintain.

Emissions

Actual emissions reductions will depend on the operational load profile. Combustion engines typically produce fewer emissions when operating closest to their best efficiency. However, in general the emissions reductions from a Tier 2 diesel *propulsion* engine to a pure LNG *propulsion* engine are predicted below:

- NO_x – At least 90% reduction
- PM – Approximately 100% reduction
- SO_x – Approximately 100% reduction
- CO_2 – Approximately 20% reduction

Hydrocarbon (HC) emissions from diesel engines are caused primarily by unburned fuel that passes into the exhaust. *Non-methane* HC emissions are regulated by the EPA as an air pollutant but *methane* emissions are not. Since LNG is nearly pure methane, a small percentage of unburned methane passes up the exhaust which is known as ‘methane slip’. Methane is a greenhouse gas and its release into the atmosphere should be minimized since it has the potential to offset the lower CO_2 benefits of LNG propulsion. Engine manufacturers are aware of the methane slip and are continually working to decrease this since is directly impacts fuel efficiency.

Capital Costs

Adapting the 144 vehicle ferry design for LNG would require a number of additional expenses above the base design:

- Acquisition of Gas Equipment (2 gas engines, 2 LNG tanks, gas piping, gas monitoring equipment, ventilation, etc)
- Design effort to adapt 144 vehicle ferry to LNG propulsion
- Classification of adapted 144 vehicle design by DNV, Lloyds or other
- Regulatory interface effort with USCG
- Installation of gas equipment at shipyard

However, since the diesel engines and fuel system would not be required the cost for these would need to be subtracted from the total. A brief cost summary is below.

Item	Cost (USD)	Source
2 Bergen C9PG, 2 x 15,000 gal LNG tanks, Gas Control System	$8.3M	Rolls Royce Estimate
Installation (gas engine, tanks, piping ventilation etc)	$3M	Estimated
Adapt 144 Vehicle Design to LNG	$1M	Estimated
Regulatory (USCG, DNV)	$1M	Estimated
2 Diesel Engines	-$2M	WSF Provided Estimate
Diesel propulsion fuel system	-$3M	WSF Provided Estimate
Estimated LNG Installation Premium	**8.3M**	

Table 1. *Differential costs for adapting the 144 vehicle ferry for LNG propulsion*

Operational costs

Fueling with LNG can significantly offset operational costs due to the much lower cost of LNG fuel compared with diesel. WSF currently fuels ferries with Ultra Low Sulfur Diesel and on some vessels biodiesel. The fuel consumption estimates are 800,000 gallons of diesel per year based on the *Issaquah*. To supply an equivalent quantity of energy, a volume of 1,360,000 gallons of LNG is required. However, LNG is much less expensive than diesel even after transportation and liquefaction costs are included. The estimated yearly fuel cost savings are summarized in **Table 2**.

	Gal/yr	Cost/gal	USD/yr	Source
Issaquah Fuel Consumption	800,000	$2.50	$2,000,000	WSF provided cost per gallon
LNG Fuel Consumption	1,360,000	$0.83	$1,128,800	Vendor estimated cost per gallon
Savings per year			**$871,200**	

Table 2. *Fuel cost savings for adapting the 144 vehicle ferry for LNG propulsion*

While the estimated savings in **Table 2** are significant, the savings could be even greater if the vessel is built to Tier 4 requirements. If the vessel were Tier 4, which it will be if built after 2014, there may well be a cost incurred by the purchase of urea for use in an SCR system. Urea consumption is typically about 5-10% of the diesel volume. Even at 5% this would add a cost of $120,000 per year at today's urea price of $800/ton.

Operational costs for maintenance of LNG engines are reportedly lower than diesel engines, according to the engine vendor. Since the fuel is cleaner, all equipment runs cleaner. However, a significant amount of control and monitoring equipment is required for an LNG vessel above what would be expected for a conventional diesel which could offset some of the savings.

APPENDIX

Figure A1. Quayside LNG bunkering with tank truck

Figure A2. Close up of quayside LNG bunkering

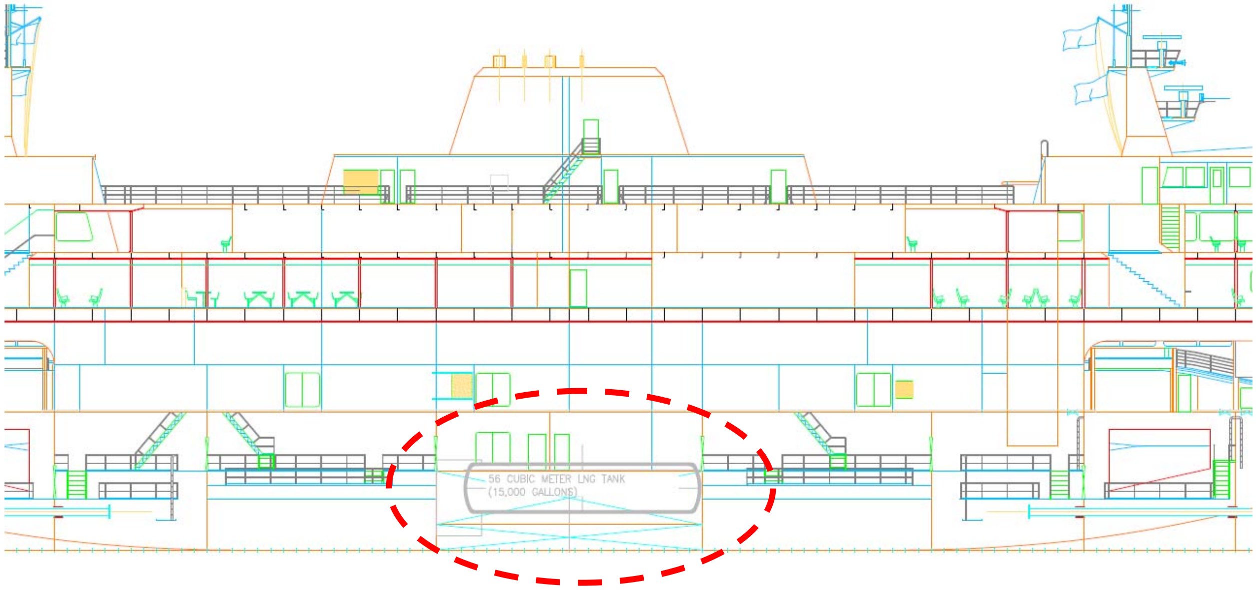

Figure A3. 15,000 gallon LNG tank below EOS

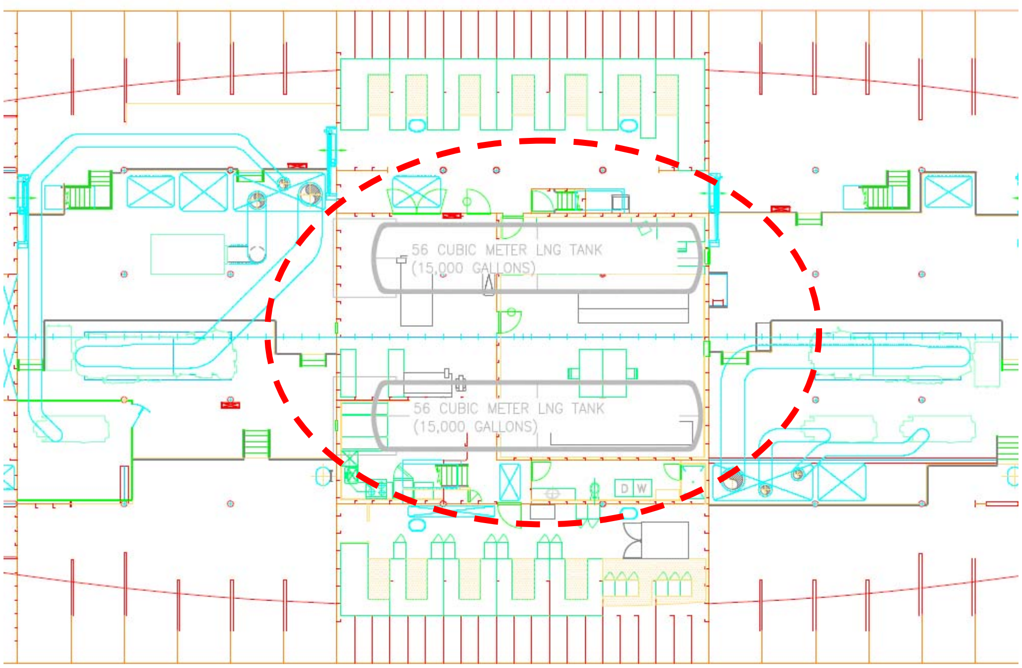

Figure A4. Two 15,000 gallon LNG tank below EOS

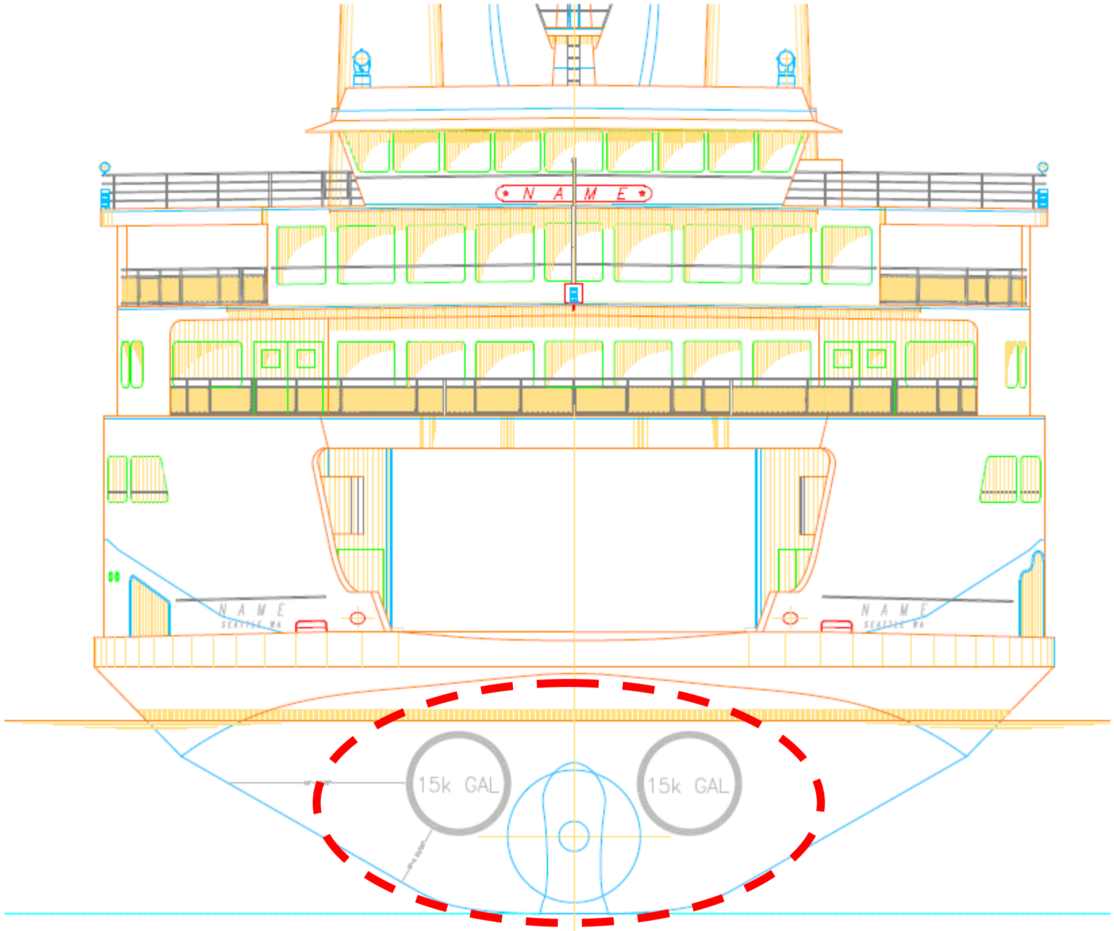

Figure A5. LNG Tanks below EOS with minimum offsets from shell

144-Car Ferry LNG Fuel Conversion Feasibility Study

Design Report

Prepared for
Washington State Ferries
Seattle, WA

File No. 11030.01
1 July 2011
Rev —

THE GLOSTEN ASSOCIATES
Consulting Engineers Serving the Marine Community

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Revision History

Section	Rev	Description	Date	Approved
All	-	Initial release	7/1/2011	DWL

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Executive Summary

Washington State Ferries (WSF) is investigating powering the new 144-Car ferries with liquefied natural gas (LNG) fuel which has potential to reduce operational costs and air emissions when compared to diesel fuel. However, converting to LNG poses technical, regulatory, and economic challenges compared to diesel. The Glosten Associates (Glosten) was tasked with conducting study to investigate both the technical and economic feasibility of such a conversion and identify regulatory risks. This study concludes that the conversion is both technically feasible and cost effective though technical and regulatory challenges remain. Capital and lifecycle costs are presented in companion report, *144-Car Ferry LNG Fuel Conversion Feasibility Study: Life Cycle Cost Analysis* (Reference 16) and design issues are presented in this report.

To support the study, Glosten has done engineering and design work culminating in a concept that has a minimum impact on vessel arrangements and operational requirements of the ferry. To convert the diesel fuelled design to LNG fuel, the diesel engines would be replaced with gas fuelled engines of similar size, power, and speed. An adequate volume of LNG fuel storage can be incorporated with the addition of a storage tank(s) on the bridge deck between the exhaust casings. All necessary gas piping and equipment, ventilation, and safety systems can be installed to support the gas fuel system without significantly affecting the general arrangements. While the conversion would require additional engineering development to be production ready, none of the design or construction modifications present a major technical risk.

One risk that has been identified is the time and cost required to obtain approval of the design by the United States Coast Guard (USCG), which does not yet have rules for gas fuelled vessels written into the Code of Federal Regulations. At the request of WSF, the USCG and Det Norske Veritas (an experienced classification society) have formally reviewed the Glosten design. Both the parties have submitted a letter to WSF with specific guidance comments to be incorporated as part of design development. No significant issues affecting feasibility were identified in the review. It is the intent that these letters establish the regulatory basis for the future review and approval of this gas fuelled vessel design. Another risk is that EPA approval of the gas engines is still in process. Though a formality, the engines cannot be sold to WSF until this approval is obtained.

A component of this study was to investigate engine exhaust gas emissions. It was found that switching to gas engines will significantly reduce emissions of nitrogen oxides ($NO_{x)}$, sulfur oxides (SO_x), carbon dioxide (CO_2) and particulate matter (PM) but increase emissions of carbon monoxide (CO) and Methane. The decreased emissions of CO_2 coupled with the increase in Methane emissions result in little change to the vessel's overall Global Warming Potential. Localized air pollution would be reduced with the reduction of NO_x, SO_x, and PM.

WSF is also considering converting the *Issaquah* class vessels to LNG. Since the design of the 144-Car Ferry is very similar to the *Issaquah* class, the key elements of the Glosten design would also be applicable (LNG tanks on the top deck between the stacks, pipe routing, propulsion repowering, etc.) to those vessels and it is therefore reasonable to assume that a conversion would be feasible. The potential benefits for fuel cost savings and emissions reduction warrant that a study specifically for that class of vessels is undertaken.

Section 1 Introduction

Washington State Ferries (WSF) is investigating powering the new 144-Car Ferries with liquefied natural gas (LNG) fuel. The use of LNG fuel has the potential of reducing fuel costs and emission when compared to diesel fuel. However, use of LNG has some technical challenges and additional equipment that contributes to a higher capital cost. In order to identify the technical challenges, design changes, and costs associated with LNG fuel use, Glosten was tasked with conducting a feasibility study for converting the existing diesel fuelled vessel design to a LNG fuelled design.

The new 144-Car Ferry class is a completed diesel fuelled vessel design that has not been built to date. The design has been carried to a production ready level, where a conversion of the existing design is more desirable than restarting the design. The design conversion would allow new vessels to be built utilizing LNG fuel, while maximizing the integrity of the current design.

An LNG design concept has been developed to retain as much of the existing design as possible while meeting the operational requirements of the ferry service as well as complying with regulatory requirements. The regulatory requirements considered for this project are the *2011 DNV Rules for Gas Fuelled Engine Installations* (Reference 1) and IMO *Interim Guidelines on Safety for Natural Gas-Fuelled Engine Installations in Ships* (Reference 2). The feasibility study considers both single fuel and dual fuel engines. This report addresses the technical feasibility of the design while a companion report, *144-Car Ferry LNG Fuel Conversion Feasibility Study: Life Cycle Cost Analysis* (Reference 16) addresses the economic feasibility.

1.1 Regulatory Review

Gas fueled engine installations are still an emerging into the global market and currently the Code of Federal Regulations (CFR's) do not include rules to direct the design and approval of gas fuelled vessels in the United States. However, rules and procedures for regulatory and Class review have been in place in other countries for several years now. To provide a basis for design, international rules have been used with the concurrence of the United States Coast Guard (USCG). The gas fueled concepts discussed in this report have been designed to be compliant with the DNV Gas Fuelled Engine Rules (Reference 1) and the IMO's *Interim Guidelines on Safety for Natural Gas-Fuelled Engine Installations in Ships* (Reference 2).

A dialog with USCG and DNV was established regarding the design standards for, and the review of, the gas fuelled vessel concepts discussed in this report. The purpose of this dialog was to address any concerns of the two regulatory bodies and to establish a path forward for review and approval of the gas fuelled vessel concepts. In the absence of specific federal regulations for gas fuelled engine installations in vessels, the USCG has indicated that a gas fuelled vessel may be submitted for review and approval as an alternative design under 46 CFR 50.20-30. It is pursuant to this regulation that the Glosten design was submitted to USCG.

The following documentation was submitted to both DNV and USCG.

1. Regulatory Review of Concepts Report (Reference 14)
2. Concept gas system Piping Arrangement drawing (Reference 15)
3. 3D General Arrangement Model (Reference 13).
4. DNV Rule Matrix addressing compliance of the concept design with the DNV Gas Fuelled Engine Rules. (Appendix of Reference 14)
5. IMO Rule Matrix addressing compliance of the concept design with the IMO's MSC.285 (86) *Interim Guidelines on Safety for Natural Gas-Fuelled Engine Installations in Ships* (Appendix of Reference 14).

The DNV and IMO rule matrices specifically identified how the concept design complied with each applicable rule of the subject regulations. Rules that were not applicable were identified as such.

All five submittals were provided to both USCG and DNV. Both parties reviewed items 1 through 3. Item 4 was reviewed by DNV only. Item 5 was reviewed by USCG only.

Following the reviews by DNV and USCG a WebEx phone conference was held with DNV, USCG, WSF, and Glosten to discuss comments on the reviewed submittals. Additionally USCG and DNV each supplied to WSF a letter stating that the concept design has been reviewed for compliance with the applicable rules and providing written record of their comments. These letters provide a basis for future review and approval of a gas fuelled vessel design. The letters from USCG and DNV have been included in Appendices B and C of this report.

The gas fuelled vessel concept described in this report is the concept design that was submitted for review. Necessary amendments to the concept design in response to the comments of DNV and USCG are included as footnotes to the effected sections of the report.

1.2 Vessel Particulars

The 144-Car Ferries will be double ended, RoRo passenger ferries for service within Puget Sound. The vessel particulars are given in Table 1.

Table 1 Vessel Particulars

Length Overall	362'-3"
Length Between Perpendiculars	335'-3"
Breadth	83'-2"
Depth at Amidships	24'-0"
Design Draft	16'-9"
Passenger Capacity	1500
Vehicle Capacity	144 Standard Autos
Classification	USCG Subchapter H

Section 2 Vessel Design

The existing vessel design is based on a propulsion system that has already been purchased. Four ship sets of controllable pitch propellers, propeller shafting, reduction gears, high speed combining shafting, and diesel engines were purchased in 2007. A goal of the conversion is to incorporate the already purchased equipment into the LNG vessel design to the greatest extent practical. The diesel engines cannot be used as they would be replaced with the gas fueled engines. However, three of the four ship sets of engines have been repurposed to power the new class of 64 car ferries that are currently being built.

2.1 Route and Operating Profile

The 144-Car Ferry may be used on several different routes. The routes vary in length but the operating profile of all of the routes is similar. The vessel starts at the dock while unloading and loading passengers and vehicles. Once loading is complete, there is a short maneuvering period to undock followed by transit at a cruise speed of 17-20 knots. When the ferry arrives at the other end of the route, there is another short maneuvering period to dock the ferry and the cycle repeats. The only significant variation of the operating profile of the various routes is the duration of the transit.

WSF provided a table of historical annual fuel consumption of the various routes. As can be seen in Table 2, the Seattle – Bremerton route has by far the highest fuel consumption of the considered routes. The high fuel consumption for this route is because it has the longest crossing and the highest vessel transit speed. As a result of these factors, the Seattle-Bremerton route was used as the design route for the tank sizing and endurance calculations in this study.

Table 2 Historical Fuel Consumption

Route	Description	Monthly Diesel Consumption (m^3)	Monthly Diesel Consumption (Gallons)
TRI	FAUNTLEROY-VASHON-SOUTHWORTH	212.7	56,200
MUK	MUKELTEO - CLINTON	170.0	44,900
BREM	SEATTLE - BREMERTON	333.1	88,000
SID	ANACORTES - SIDNEY	268.8	71,000
SJ	ANACORTES - FRIDAY HARBOR	208.2	55,000

The durations and engine loads during the docked and maneuvering periods were taken from Reference 3 for a direct drive version of the 130-Car Ferry design. It was assumed that the docked and maneuvering loads would not be significantly different for the 144-Car Ferry. The engine load during transit was taken from Reference 4 for the 144-Car Ferry at 17 knots. The duration at transit was calculated for the route by deducting the maneuvering time from the total crossing time of 60 minutes.

Table 3 Seattle - Bremerton Operating Profile

Mode	Total Propulsive Power (Brake Power)		Duration
Docked	379 kW	(508 HP)	20 Minutes
Maneuvering	781 kW	(1,048 HP)	10 Minutes (Total)
Transit at 17 kts.	3,441 kW	(4,615 HP)	50 Minutes

2.2 Propulsion System

The 144-Car Ferry design has a mechanically-driven, controllable pitch propeller at either end. The two main propulsion engines will be located in separate machinery spaces and will be combined through reduction gears with a high speed shaft. The reduction gears will be designed for the combined full power output of both engines, thereby allowing either propeller to be driven with both engines. During normal operation, both engines will be online and equally share the propulsive load. While transiting, the bow propeller will be fully feathered and declutched from the propulsion drive system. While maneuvering, both propellers will be used.

2.2.1 Gas Engine Selection

Currently there are two types of marine gas engines available on the market in the power range required for this project. These engines are dual fuel engines and single fuel (gas only) engines. The dual fuel engines can be operated on either gas fuel or liquid (diesel) fuel and can switch between fuels while in service. Additionally the dual fuel engines use a small amount (approximately 1%) of diesel fuel as a pilot fuel to ignite the gas when operating on gas fuel. The single fuel engines use only gas fuel and cannot operate on diesel fuel. Single fuel engines are spark ignition engines.

There are two safety categories of gas fuelled propulsion systems: inherently safe or not inherently safe. An inherently safe gas engine is an engine where all of the on-engine gas supply piping is double walled pipe. Engines without the double walled gas pipe are not inherently safe.

An engine that is not inherently safe must be located in an emergency shutdown (ESD) protected engine room. This means that if an abnormal condition involving a gas hazard is detected; all equipment that is not of explosion protected design, including the engine, must immediately shut down. This requires that all vital equipment located in an ESD protected engine room must be explosion proof. Because the gas piping is enclosed in a double walled pipe, in an inherently safe engine room the equipment in the engine room does not need to be explosion proof. Typically when a non-inherently safe engine is used, the engine is located in a small ESD engine room and the majority of auxiliary equipment is located in a separate machinery space so that it does not need to be explosion proof. This type of machinery arrangement is a major driver of the vessel’s arrangement and therefore structural arrangement. Because this vessel is an almost completed detailed design and a substantial amount of equipment is located in the engine rooms, ESD protected engine rooms are not practical. For this reason engines that must be located in ESD protected engine rooms were not considered in this design.

At the time of this study the only engine manufactures with gas fuelled inherently safe engines on the market and of appropriate power are Rolls Royce and Wärtsilä. Both manufacturers were considered in this study. The Rolls Royce engine considered is the single fuel Bergen C26:33 L9PG developing 2,200 kW (2,950 HP). The Wärtsilä engine that was considered is the dual fuel 6L34DF engine. The 6L34DF will need to be derated from 2,700 kW (3,620 HP) to 2,300 kW (3,084 HP). The fuel consumption was calculated to be approximately 4% higher for the 6L34DF rated at full power and operating at lower loads.

At the time of publication of this report, other manufacturers are developing inherently safe, gas fuelled engines, and there may be additional engines that will become available over the next few years. In this study however, only engines that are currently on the market and have Class approval were considered.

It should also be noted that both manufacturers have stated that they have not yet completed the process of getting EPA certification of their engines. All marine engines need to be certified by the EPA for emissions purposes. Since gas engines for marine use are still new to the US market, this process is still ongoing and a specific date for approval was not available. The EPA was not consulted for this report, but this issue will need to be resolved before either manufacturer can sell these engines in the US. While this issue is a formality, it presents a possible schedule risk to WSF.

2.2.2 Gears and Shafting

Replacement of the propeller, shafting, or gear due to incompatibility with the gas engine would increase cost and cause additional design changes. The existing propellers and shafting are rated for the power output of the previously purchased EMD engines (2,237 kW or 3,000hp). The power output of the gas engines was selected to be compatible with the purchased propellers and shafting so to that no changes are required. The reduction gears used in the current design are Falk gears with two inputs and a single output specifically designed to integrate into the drive train. The reduction ratio of the Falk gear is ~5:1 to reduce the 900 RPM EMD design engine to the 180 RPM that the propeller rotates at its optimum design point. The Falk gear geometry has both a vertical offset (44") and a horizontal offset (30") to match the engine output shaft, the combining shaft, and the propeller shafting geometry.

The Bergen engine operates at 900 RPM and no alteration to the reduction gear would be required. Slight height modifications to the engine foundation would be required to maintain vertical alignment with the gear.

The Wärtsilä engine operates at 750 RPM and to maintain the propellers 180 RPM design speed a new gear would be required. Wärtsilä cannot produce a gear with the required geometry and reduction ratio to replace the Falk gear. For this report it is assumed that Falk or a different gear manufacturer can supply the required gear. With the de-rating of the Wärtsilä engine to 2,300 kW (3,084 hp) the existing shafting will not be overloaded.

2.2.3 Engine Response and Maneuvering

While maneuvering and docking the engine loads change fairly quickly. Historically gas fuelled engines have slower response times than diesel fueled engines. It was necessary to look at the loading response times of the engines to see what impact engine load response might have on the maneuvering of the vessel.

At the time of publication, a load response curve was not available for the Bergen C26:33L9PG engine, however, Rolls Royce was able to provide by email an estimate of the load response performance of the engine. Rolls Royce has indicated that the C26:33L9PG engine can increase load at 3% per second. Rolls Royce recommends that the engines be loaded in steps of 0-85% and 85-100%.

Wärtsilä was able to provide the response curves for the 34DF engines. The engine loading capacity response curves can be seen in Figure 1. Based on these curves, the engine can be loaded from 20-85% at approximately 1.3% per second and from 85-100% at approximately 0.3% per second when operating on gas. Instantaneous power steps of 20% are possible from 0% power to 30% power and decreasing instantaneous power steps (down to 10%) are possible as power is increase above 30%. The response times while operating the dual fuel engine on diesel fuel are faster than when operating on gas fuel. It was assumed that the vessel will be operating on gas under normal conditions. However, in an emergency maneuver, the engine could be switched to diesel fuel to achieve a faster response time.

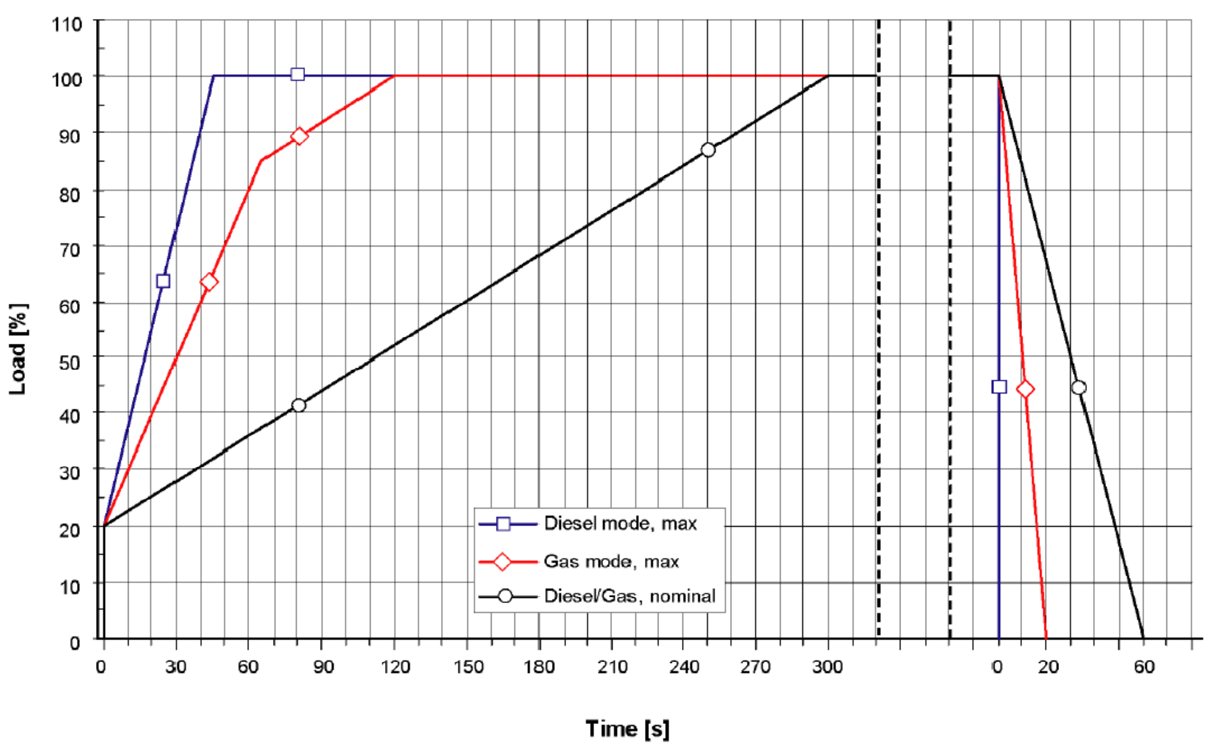

Figure 1 Wärtsilä 34DF engine loading capacity

The gas engine response times are slower than those of a typical two-stroke diesel engine such as the EMD engines in the existing design. The slower response times will have an effect on maneuvering and docking operations. It is likely that the operator will need to adjust their maneuvering and docking procedure to compensate for slower engine response times of the gas engines.

Rolls Royce has noted that the response of the Bergen engine and the response of the CP Propeller control system need to be reviewed in future design phases to ensure their compatibility. Some changes to the CPP control system may be necessary but it could not be fully determined due to time constraints of this study. The compatibility of the CPP control system and Wärtsilä engine should also be confirmed.

2.3 Gas Fuel Specification

The vessel will be fueled with liquefied natural gas (LNG). LNG is used today as a transportation fuel but the market is still small compared to most other alternative transportation fuels. LNG is typically transported by truck from liquefaction facilities to the fueling stations.

LNG is in limited use in Washington State today, but if a large enough market existed in the Puget Sound area, a supplier would build a liquefaction plant. Currently two liquefaction facilities exist on the Washington/Oregon border and another on the Canadian side of the Washington/Canada border. One LNG fueled ferry similar in size to the new 144-Car Ferry would likely consume enough LNG to justify a Puget Sound liquefaction plant. It is possible to transport LNG from the existing liquefaction facilities to supply the ferry service until a local facility is built.

The specification of the LNG that will be delivered is somewhat dependant on the liquefaction plant providing the fuel. Clean Energy Fuels, a national LNG fuel supplier has indicated that LNG supplied from the natural gas pipeline in the Puget Sound region could be produced to the fuel specification shown in Table 4.

Table 4 Typical West Coast Pipeline LNG Fuel Specification.

Gas Contents (% by Volume)		
CH_4	95.70	%
C_2H_6	2.70	%
C_3H_8	0.60	%
C_4H_{10}	0.08	%
N_2	0.90	%
Gas Properties		
Density (at 0°C & 101.325 kPa)	0.74866	kg/m^3
Lower Calorific Value	49165	kJ/kg

2.4 Range and Endurance

Initially it was intended to provide the vessel with sufficient LNG storage for 10 days of endurance on the longest route. This endurance was chosen primarily to provide a large margin in the vessel's bunkering schedule in order to accommodate any unanticipated delay in LNG fuel delivery. Late in the project one of the tank vendors and a gas supplier recommended reducing the amount of storage because they thought it may be difficult to keep the fuel cold enough with the desired bunkering schedule and endurance. As a result of these recommendations, both the Rolls Royce and the Wärtsilä designs have been updated to have 7.5 days of gas fuel endurance. This endurance will reduce the size of the tanks but still provide flexibility in the operating and bunkering schedule.

In the next phase of the design it will be necessary to revisit the vessel endurance. Working closely with the tank manufacturer(s) it will be necessary to determine the maximum endurance that can be achieved while keeping the fuel sufficiently cold. Working closely with the LNG supplier(s) it will be necessary to structure the fuel delivery such that the fuel can be delivered reliably without interruptions.

The fuel consumed for the Seattle – Bremerton route over 7.5 days was calculated for both the Rolls-Royce and the Wärtsilä engines using the operating profile and the specific fuel consumption information from the vendors. It was assumed that the vessel would make 16 crossing per day between Seattle and Bremerton, per the current schedule.

The specific fuel consumption was extrapolated using a second order polynomial curve fit to the points given in the vendor's technical information, because the specific fuel consumption data was only given for a few engine load levels.

The energy density of natural gas depends on the gas makeup and can vary significantly. Because of this, specific fuel consumption for natural gas engines is given in energy based units (mJ/kWh) rather than mass based units. The consumption of diesel oil in the dual fuel engines is given in mass based units (g/kWh).

Using the energy density of the fuel as given in Table 4, the daily fuel consumption of the two different engines was calculated. The calculated values can be seen in Table 5.

Table 5 Daily Fuel Consumption

Engine	Daily LNG Consumption	Daily LNG Consumption		Daily Diesel Oil Consumption	
	(mJ/Day)	m^3	gal	l/Day	gal/Day
Bergen C26:33 L9PG	385,839	18.98	5,014	0.0	0.0
Wärtsilä 6L34DF*	444,574	21.03	5,556	218.7	57.8

*Engine is assumed to be derated to 2,300 kW (3,084 HP)

LNG tank filling and storage must be careful calculated and controlled due some unique properties of LNG. Because LNG is cryogenic, delivered at -163°C (-262°F), the tanks must undergo a special cool down procedure before they can be filled with LNG for the first time. In the cool down procedure the tanks are slowly cooled with liquid nitrogen to bring them down to temperature. Once the tanks are filled with LNG, they need to be continuously kept cold. In order to keep the tanks cold, a minimum amount of LNG needs to remain in the tanks at all times. If the tanks are completely emptied, they will warm up and the cool down procedure is required before than can be loaded again. Typically the amount of fuel that must remain (innage) is 5-10% of the tank's volume. Based on the documentation from both tank vendors, the Rolls Royce tanks will have an innage of 10% while the Wärtsilä tank will have an innage of 5%.

Additionally, the density of LNG changes substantially with temperature which makes it necessary to account for the expansion of the liquid in the storage tank. It is theoretically possible for the LNG to reach a temperature of -130 °C (-202°F) before the tank's pressure relief valves open to vent the tank. This temperature is referred to as the reference temperature. The regulations require that the maximum fill level of the tanks is such that at the reference temperature, the tank will not be more than 98% full. Because the fuel is subcooled to -163°C (-262°F) when it is delivered from the trucks, the tanks can only be loaded to 86% full to prevent the tank from being liquid full when the gas warms up to the reference temperature.

Because of the innage and the 86% maximum filling, the amount of consumable volume in the tanks is only 76-81% of the tank's geometric volume at the delivery temperature of -163°C (-262°F). Using this information, the required geometric volumes of the tanks was calculated for both engines. The required tank volumes are given in Table 6. Note that in accordance with the regulations the dual fuel engine does not require a redundant gas fuel system; therefore a single LNG storage tank is permissible.

Table 6 Required Tank Size

Engine	Total Consumable Fuel Volume		Number of Tanks	Required Tank Volume		Selected Tank Geometric Volume	
	m^3	gal		m^3	gal	m^3	gal
Bergen C26:33 L9PG	142.4	37,618	2	93	24,568	95	25,096
Wärtsilä 6L34DF*	157.7	41,659	1	194	51,249	194	51,249

*The engine is assumed to be derated to 2,300 kW (3,084 HP)

The LNG storage tanks proposed by Rolls Royce are two 95 m^3 (25,096 gal) custom tanks. The storage tank proposed by Wärtsilä is 194 m^3 (51,249 gal) and is from a catalog of standard tank designs. Both tanks are of sufficient size to provide 7.5 days endurance on the Seattle – Bremerton route.

2.5 Gas Fuel System

The gas fuel system includes the LNG storage tanks, gas vaporization equipment, gas distribution system, and bunkering system. The general gas system arrangement is shown in Figure 2. Certain aspects of the gas fuel system arrangement vary slightly, depending on whether gas only or dual fuel engines will be used. Where there are differences, both configurations will be addressed specifically.

The gas system will be supplied as part of the scope of supply of the engine vendor.

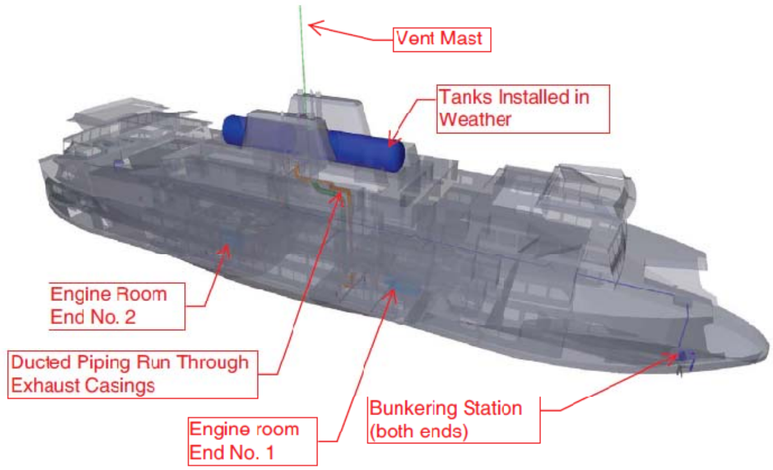

Figure 2 Gas System Arrangement

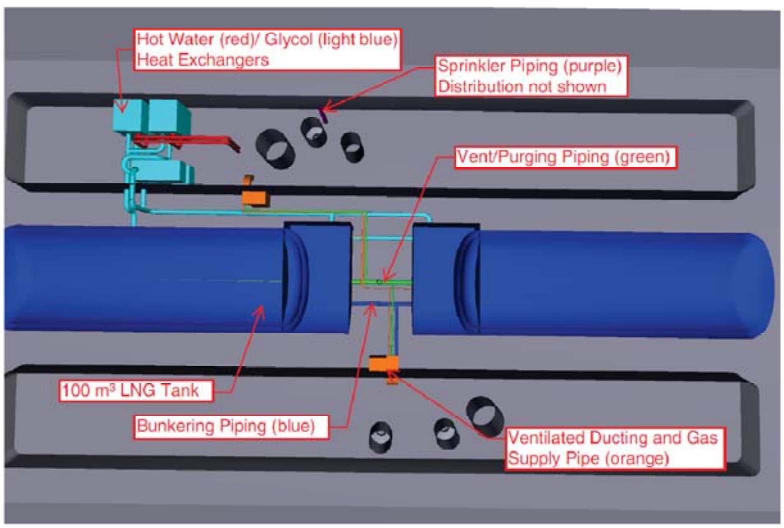

Figure 3 Storage Tank Arrangement

2.5.1 Gas Storage

The LNG will be stored in a single 194 m^3 (51,249 gal) tank if dual fuel engines are used or in two 95 m^3 (25,096 gal) tanks if single fuel engines are used. The tank sizes were determined based on the endurance of the vessel fuel consumption for the engines as well as the availability of standard tank sizes. The sizing and selection of tanks is discussed in further detail in Section 0.

The LNG storage will be located be located in the weather on the Bridge Deck of the vessel. Locating the tanks on the Bridge Deck is preferable to locating them below the main deck for several reasons.

- The vessel's hull structure will not need to be redesigned to accommodate tanks inside the hull.
- The USCG has indicated that they prefer that the tanks be located in the weather and that they are not located beneath passenger accommodations.
- The cost of installing the tanks on an open deck is significantly less than to install them inside the hull.

Reinforcement of the deck and supporting structure will be required to support the tanks but major changes to the vessel's structure are not required. The extent of structural modifications is further discussed in Section 2.8 of this report.

The tanks will be located on the centerline of the Bridge Deck between the exhaust casings. This places the tanks in a location such that they will be in the weather on an open deck and will not be below any passenger accommodation spaces. See Figure 3 for the location of the tanks. The tanks will be double shell vacuum-insulated pressure vessels, with a design pressure of 7.5 barg (109 psig) and an operating pressure of 5 to 6 barg (73 to 87 psig). A gas tight tank room will be integral to one end of each of the tanks, and will contain all the gasification process equipment. The tanks will be equipped with pressure relief valves to prevent over pressurization of the tank. The relief valves will vent the tank to the gas vent mast discussed in Section 2.6.2.1. The LNG storage tank vendor will be responsible for ensuring that the tanks are designed to the applicable DNV and USCG regulations and that any required certificates and documentation are provided.

The LNG storage tanks will be filled at most to 86% of the available volume. This is to allow for expansion of the LNG with changes in temperature. The space above in the liquid level in the tank will be filled with gas vapor. This space is referred as the gas cushion.

2.5.2 Gas Distribution System

Each tank will have an attached, gas tight tank room that will be integral with the outer shell of the tank. Each tank room will contain a pressure building unit (PBU), a LNG Vaporizer, and a Natural Gas (NG) Heater, as well as gas delivery piping and valves. All of the gas piping and equipment that processes liquefied gas will be located inside of the tank room. This does not include the bunkering pipes which also carry liquefied gas, and are located outside of the tank rooms. The bunkering system is discussed separately in this report.

In normal operation, LNG fuel is conducted to the LNG Vaporizer where it is evaporated to natural gas vapor at a temperature of approximately -140°C (-220°F). The gas is then conducted to the NG Heater where it is heated to the required temperature for the engine fuel supply between 5°C and 40°C (41°F and 68°F). The heated gas is then delivered to the engine by way of the piping and a gas supply unit (GSU) which is separately discussed in this report. When there is a need for rapid increase in engine output, fuel gas can also be taken directly from the gas cushion at the top of the storage tank. Gas taken from the gas cushion will be conducted through the NG heater where it is heated to the required temperature for the engines.

In the event that the LNG Vaporizer is inoperative, the LNG vaporizer can be isolated and the fuel gas system can use the PBU as a vaporizer. The PBU is a vaporizer used to build the pressure in the tank to the operating pressure. If the PBU is used to supply fuel gas, the vessel will be restricted to operation at reduced power due to the limited gas output of the PBU.

Each gas system is fitted with a tank valve that can be used in an emergency to shut off supply of liquefied gas. Each gas system is also fitted with a master gas valve that can be used for emergency shutdown of vaporized gas. Typically the master gas valve will be used for shutting down the gas supply unless an alarm has occurred inside the tank room. Alarms and emergency responses are further discussed in Section 2.9.

The liquefied gas will be delivered to the pressure build up unit and the fuel vaporizer by a pipe that comes off the bottom of the gas storage tank. The tank valve for shutting off the liquid line will be a remote operated valve that will be located near the tank outlet. The vaporizer and gas heater will utilize a hot water/glycol system to provide the necessary energy for vaporizing and heating the gas. Once vaporized and heated, the gas will exit the tank room through the gas supply piping that delivers the gas to the engine rooms.

The gas supply piping will be arranged with the master gas valves on the Bridge Deck close to the tank rooms. From the master gas valves onward, the piping system will be the same for both the single fuel and the dual fuel engines configurations. Because the dual fuel gas system only utilizes a single tank, the gas distribution system upstream of the master gas valves will be somewhat different for the two types of engines.

In the gas system for single fuel engines, the gas supply piping will lead from each of the tank rooms to the master gas valves located just outside of each of the tanks rooms. Between the tank rooms and the master gas valves will be a crossover pipe with a normally closed, remotely operated valve that connects the gas supply lines from both tanks. This crossover will be used to supply both engines from one of the two tanks in the event that supply from the other tank is unavailable. It should be noted that the Rolls Royce gas distribution system does not have enough capacity to supply gas to both engines at full capacity with one tank off line. This is due to the way the gasification equipment was sized. If redundancy is desired it may be possible to increase the gasification capacity. However, DNV and USCG have both indicated that the ability to operate both engines at rated power from a single tank is not required as a condition of Class or regulatory compliance.

In the gas system for the dual fuel engines, the gas distribution piping will lead from the single tank room and branch to two master gas valves, one for each engine room, located just outside of the tank room. From the master gas valves onward the gas supply piping will be identical to the single fuel gas supply piping.

From the master gas valves, the gas supply piping to the End No. 1 Engine Room will be run to the starboard exhaust casing, and the supply to the End No. 2 Engine Room will be run to the port exhaust casing. Inside the casings, the gas supply piping will be run inside ventilated ducts to the Gas Supply Unit (GSU) located in each of the engine rooms. The GSU will be located inside a gas tight enclosure in the engine room. The GSU enclosure will be integral with the ventilated duct. There will be one GSU and GSU enclosure in each of the engine rooms. The gas distribution piping will be led inside of a ventilated duct from the GSU enclosure to the engines. See Figure 2 and Figure 3 for the general arrangement of the gas system and Figure 4 for the arrangement in the engine room.

All of the gas supply piping will be low pressure piping, with the gas pressure not exceeding 7.5 barg (109 psig)and typically being 5 to 6 barg (73 to 87 psig). Pressure relief valves inside the GSU will ensure that the gas pressure does not exceed the maximum allowable pressure.

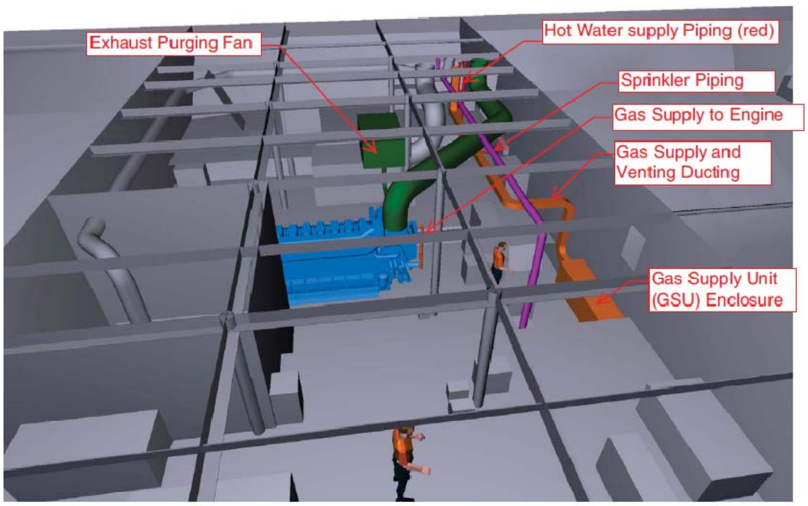

Figure 4 Engine Room Arrangement

2.5.3 Gas Supply Unit

The gas supply unit (GSU) will consist of the double block and bleed valve, gas filter, pressure control valve, and a nitrogen purging connection. On either side of the double-block-and-bleed valve will be a ventilation valve that allows the gas supply piping upstream and downstream of the double-block-and-bleed valve to be vented to the gas vent mast. The nitrogen injection valve will be located upstream of the double-block-and-bleed valve, to facilitate inerting the gas supply line between the double-block-and-bleed valve and the storage tank, as well as from the GSU to the engine.

The GSU for each engine will be installed inside a gas tight enclosure in the respective engine room. The ventilation ducting around the gas supply piping will be connected to the GSU enclosure thereby ventilating the enclosure. The GSU enclosure will be considered a *Zone 1 Hazardous Space*, per the requirements of References 1 and 2, and will not have access doors. Maintenance and service access to the enclosure will be through a bolted hatch that will only be opened when the gas supplying line has been inerted with nitrogen. After the gas supply lines are inerted, the GSU enclosure is not a hazardous space.

Wärtsilä offers a packaged GSU inside an enclosure similar to what shown in Figure 5. This packaged unit will be part of the scope of supply of the Wärtsilä system. Typically for the 34DF engines the GSU enclosure is oriented horizontally. However, Wärtsilä has indicated that it can be packaged into a vertical orientation to save space in the engine room. Rolls Royce does not offer a packaged GSU enclosure. The enclosure will need to be designed and then fabricated by the shipyard.

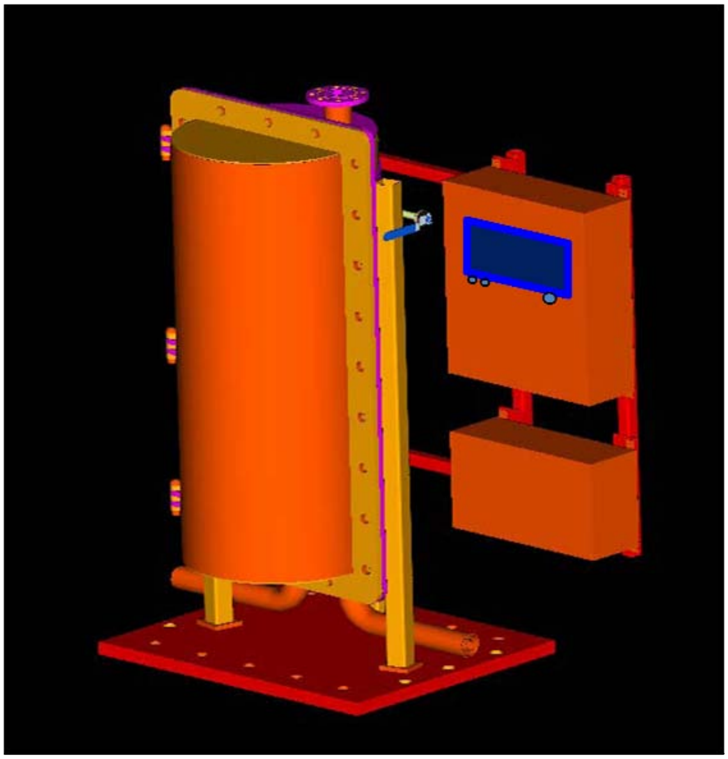

Figure 5 Wärtsilä Packaged GSU and Enclosure

2.5.4 Glycol System

The LNG vaporizer, gas heater, and pressure build up unit will be supplied with heat from a closed loop 50/50 glycol system. The glycol system heat exchangers and pumps will be located in the exhaust casing on the bridge deck as can be seen in Figure 3. The hot water heating system in the current vessel design will be used to heat the glycol through heat exchangers. Wärtsilä suggested that the low temperature jacket water system may be used to heat the glycol system, however this information was not provided in time to be included in this study. It would be worthwhile to investigate this option for both systems in the next phase of development as it would increase the waste heat utilization.

Wärtsilä offers a skid mounted glycol system consisting of a heat exchanger, two circulating pumps, and the necessary valves and piping to connect the system. The Wärtsilä gas system requires approximately 230kW of energy for the PBU and 345 kW of energy for the vaporizer to produce the required amount of gas to operate both engines at MCR. Clarification was not provided as to whether the PBU and vaporizer demands are simultaneous.

Rolls Royce does not offer a packaged glycol system. A closed loop glycol system will need to be designed and procured separately from the engine and gas system. The glycol system will consist of two hot water/glycol heat exchangers, two circulating pumps, and the necessary valves and piping to connect the system. The Rolls Royce gas system requires a total of 270 kW of energy to produce the required amount of gas to operate both engines at MCR.

Both systems will be pressurized with nitrogen to 10 barg (145 psig) in order to prevent gas from entering the glycol system in the event of a leak. Any glycol that enters the gas system will instantly freeze and will not reach the engine. A loss of pressure in the glycol system indicates a leak and will cause alarms to sound and the system with the leak to shut down.

2.5.5 Bunker Station and Bunkering Process

Washington State Ferries bunkers their vessels at night while they are tied up at the dock, between the last run of the day and first run of the next day. There are no passengers or vehicles on the vessel during bunkering. Bunkering with LNG will follow the same approach. The typical bunkering cycle will consist of a truckload (~10,000 gallons or ~37.8 m^3) of LNG fuel delivered every 2 to 3 days. The design, however, does have sufficient fuel capacity to operate at least 7.5 days without bunkering.

The vessel will have a bunkering station located at both ends of the vessel on the Main Deck at the side shell (see Figure 6). This location is open to the weather and will have good natural ventilation. The vehicle space, which is open on both ends and has large openings in the sides, will be naturally well ventilated to prevent the buildup of natural gas vapors.

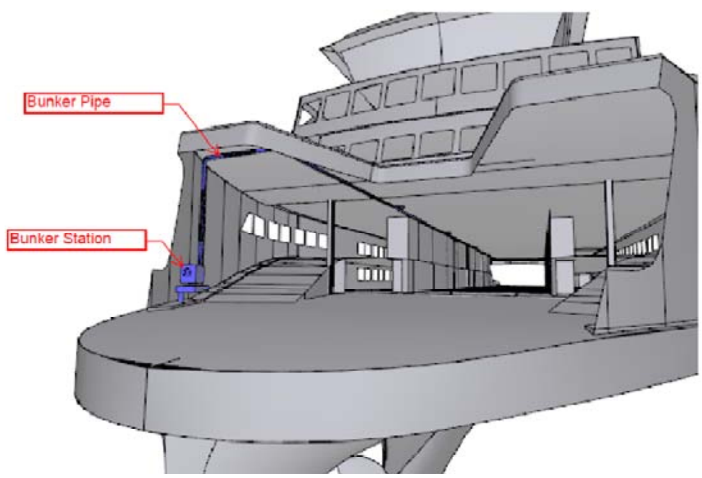

Figure 6 Bunkering Station

The bunker station will consist of a shore connection, a pressure gauge, a manual stop valve, and a remotely operated stop valve. Underneath the bunkering station will be a stainless steel drip tray. The drip tray will drain overboard through the Main Deck and hull plating where it overhangs the water. The drain pipe will be constructed of cold resistant stainless steel. The deck and hull penetrations will be sleeved and the drain pipe will be thermally isolated from the vessel's structure. The overboard will be installed such that any liquid discharged from the drain is directed away from the vessel's hull.

The bunker piping will be routed from the bunker station up to the overhead of the vehicle space, where it will be run to the exhaust casing at approximately amidships. Inside the casing, the piping will be routed up to the tanks alongside the gas supply piping inside a ventilated duct. The bunker piping inside the casing will be double wall vacuum jacketed pipe. Because the vehicle space is an open space, piping in the vehicle space will be single walled pipe.[1]

The bunkering station itself and the bunker piping that runs up the side shell of the vehicle space will be located less than 760 mm (29.9 in) from the side shell in apparent conflict with the applicable rules.[2] Once the bunker pipe reaches the overhead of the vehicle space, it will immediately run inboard to where it will be more than 760 mm (29.9 in) inboard of the side. Bunkering will only occur while the vessel is at the dock. While the vessel is underway, the bunker pipe will be inerted with nitrogen in accordance with the rules.

There will be over 45 m (150 ft) of bunker piping between the point where the bunker pipe reaches the vehicle space overhead and the storage tank. The piping will have sufficient flexibility that any damage to the bunker station from an accident or collision will not propagate to the tank connection. Additionally, the bunker station and the piping will be mechanically protected by the ship's structure, bollards, and/or steel cages to prevent damage by vehicles.

Bunkering will be carried out using a mobile transfer pump trailer to transfer the fuel from the tanker truck to the ship. During bunkering operations, the transfer pump trailer and the tanker truck will be located on the shore side vehicle loading ramp, and be connected to the bunkering station with a portable hose. The anticipated rate of fuel transfer is 68.1 m^3 per hour (300 gallons per minute). During liquid transfer, pressure will be regulated in the storage tank by spraying cold liquid into the gas space in the tank to collapse the gas pocket. No gas will be released during bunkering.

Once liquid transfer is complete, the bunkering line will be blown out with heated natural gas vapor delivered from a vaporizer on the transfer pump trailer. The heated gas will push liquid into the tanks, then vaporize any remaining liquid in the line and blow it up to the vessel's storage tanks. The vapor will be introduced into the tanks through the bottom fill lines, so that the LNG in the tanks causes the gas to condense and minimize the pressure build up in the tanks. Once the bunkering lines have been blown out, they will be purged to the vent mast with nitrogen injected at the bunkering station.

The bunkering station will be shielded from all accommodations spaces by A-60 boundaries. Because of the location of the bunkering station, it is not practical to shield the bunkering station from the vehicle space. Bunkering will only occur when the ferry is out of service, so there will be no passengers or vehicles in the vehicle space during bunkering. Additionally,

[1] DNV noted that flanges in bunkering pipes need to be protected against liquid spills onto ship structure. To accommodate this, bunker pipe joints should be welded wherever possible. Joints that cannot be welded will require spill containment. Vacuum insulation is not considered containment. These piping details should be developed in future phases of the design.

[2] DNV and USCG have stated that the short run of bunkering piping less than 760mm from the side is acceptable.

the vehicle space will be made entirely of steel decks and bulkheads of A-0 or better, and all doors to the vehicle space will be A-60. Furthermore, the vehicle space will be protected with a zonal deluge sprinkler system. As a result of these factors, it is our position that, at the time of bunkering, there will be minimal threat that a fire at the bunkering station would spread into the vehicle space or to other parts of the vessel.[3]

2.6 Ventilation and Bleed Vents

The ventilation and bleed systems have been designed to meet all of the applicable DNV rules (Reference 1) and IMO Resolution MSC.285 (86) (Reference 2). Although slight variation may occur between single or dual-fuel configurations, the arrangements will be very similar for both systems.

2.6.1 Ventilation

2.6.1.1 Gas Pipes

To achieve the required ventilation, a duct will be provided around the gas supply line and the bleed vent line running to each engine room GSU as well as the portion of the bunkering line that is inside the exhaust casing. These ducts act as a secondary barrier for containment for the gas piping run through all enclosed spaces.

Each ventilation duct will be one continuous duct from the engine to the Bridge Deck. The ventilation air will be drawn into the on-engine double wall piping from the engine room. The double wall of the on-engine piping will be connected to ducting around the gas supply pipe leading from the GSU enclosure. From the GSU enclosure, the duct enclosing both the gas supply line and bleed vent line will be lead inside the exhaust casing all the way to the Bridge Deck, where it penetrates the casing. Once the gas piping exits the casing, the piping will be on open deck and ventilation ducting is not required. On the starboard side of the vessel, the bunker piping will also run inside the duct from the Upper Car Deck overhead to the Bridge Deck.[4]

On the Bridge Deck, the ventilation air will be exhausted by a fan in a non hazardous zone directly after the duct penetrates the casing. It will be exhausted on deck in a location away from any potential sources of ignition. The fans will be sized such that the air will be drawn through the GSU enclosure at a rate of 30 air changes per hour to achieve sufficient ventilation.[5]

Because the ventilation air is drawn in from the engine room, gas detectors will be installed in the engine rooms.

[3] DNV and USCG have accepted the arrangement of the bunkering station. USCG has stated that the OCMI may put a restriction on the COI stating that bunkering may only be done with no vehicles or passengers onboard.
[4] DNV has stated that the ventilation duct around the gas distribution piping inside the machinery space must be separate from the duct around the bunker pipes outside the machinery space. A separate ventilation duct with a separate exhaust fan will need to be added for the bunker pipe to accommodate the DNV requirement.
[5] DNV has stated that redundant fans are required for the gas ventilation fans. A second fan will need to be added to each duct.

2.6.1.2 Machinery Spaces

The engine rooms must also be sufficiently ventilated. Air will be drawn through a louver on the Bridge Deck and down the casing, and will be exhausted out the top of the stacks. The supply and exhaust ventilation for each engine room will each be powered by two equally sized fans (four fans total per engine room). For each engine room, one supply and one exhaust fan will be powered by a separate circuit off the main switchboard from the other two fans. This configuration provides redundancy in the event of a failure, and ensures that a minimum level of 50% of design ventilation will be maintained.[6]

2.6.1.3 Tank Rooms

DNV rule Section 3/I 301 (Reference 1) states that tank rooms located below deck must be ventilated. Because the tank rooms will be located on a weather deck, we propose that the tank rooms be equipped with a ventilation system that will be secured under normal operation. The intention of securing the ventilation is to reduce the corrosion of the tank room and equipment caused by the introduction of salt air into the tank room. The ventilation system would only be operated in the event that a gas detector in the tank room alarms or to make the space safe for entry for maintenance.[7]

2.6.1.4 Exhaust System Purge

A gas purging fan is also required for each engine exhaust system. Each fan will be sized to quickly purge the volume of the exhaust pipe 3 times. Purging will be done before each engine start-up or after a failed start to maintain a gas-free exhaust system and prevent ignition of any built-up gasses.

2.6.1.5 Intakes and Exhausts from hazardous areas[8]

In accordance with Reference 2 hazardous area Zone 1 areas are any locations:

- Within 3m (9.8 ft) of any gas tank outlet, gas or vapor outlet, bunker manifold valve, gas valve, gas pipe flange, gas pressure relief openings
- Within 1.5m (4.9 ft)of a tank room opening
- Within 3m (9.8 ft) of the bunker station up o a height of 2.4m (7.9 ft) above the deck

Hazardous Zone 2 areas are any locations:

- Within 1.5m (4.9 ft) of a Zone 1 area.

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[6] DNV has stated the requirement for redundant engine room ventilation is intended for ESD engine rooms only. Because the engine rooms are inherently safe, the engine room ventilation system may remain as designed for the existing diesel fuelled vessel design.
[7] USCG has stated that an analysis demonstrating equivalent safety of the tank room would be required to secure the tank room ventilation system in normal operation. In light of this requirement, the tank room ventilation system would be normally on.
[8] USCG has stated that they have a slightly different definition of hazardous zones. These zones are defined in their written comments attached to this report.

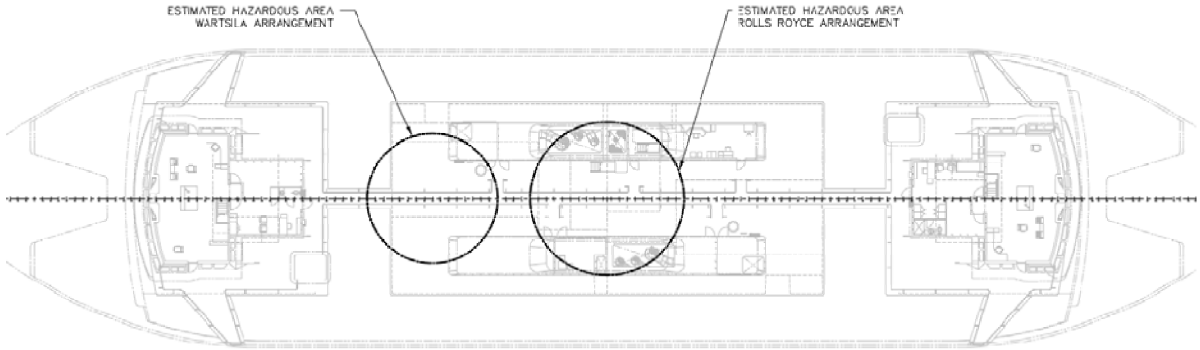

Figure 7 Hazardous Areas on Bridge Deck

Ventilation air intakes may only be located in non hazardous locations. Because no HVAC system drawing was available, it could not be confirmed that all ventilation intakes meet this requirement. However, the extent of hazardous areas has been minimized as much as possible. An estimation of the hazardous area on the Bridge Deck is shown in Figure 7. The actual extent of the hazardous area will depend on the detailed arrangement of the gas piping. Any ventilation intakes within the hazardous area would need to be relocated to a non hazardous area.

The engine room ventilation intakes in the existing design are located at the ends of the exhaust casings. With the arrangement of the Rolls Royce system, these intakes are not anticipated to be located in a hazardous area. In the arrangement of the Wärtsilä system the Number 2 end engine room intake will likely be affected and will require modification to ensure no intake louver will be located in the hazardous area. This may require that all the ventilation intake louvers be located on the outboard side of the casing.

All ventilation exhausts must be located in an area with a hazardous rating of no greater than the space served by the ventilation system. Again, the locations of all the ventilation exhausts could not be determined. Any ventilation exhausts located within a hazardous area would need to be relocated to a non hazardous area. Because the engine room exhausts are located in the top of the stack, they should not need to be relocated.

In addition to ventilation intakes and exhausts, openings to non hazardous spaces may not be located in a hazardous area unless they are fitted with an air lock. This may require that the spaces with access opening on the inboard side of the casings from the Bridge Deck may need to be relocated or fitted with an airlock. The extent of the effected openings will be dependent on the detailed arrangement of the gas piping system on the Bridge Deck. However, it is anticipated that no more than four opening will be affected.

2.6.2 Gas Vents

There are several gas vents in the gas system. The vents are either from pressure relief valves or from bleed lines for purging gas supply lines. All the gas vents are lead to a gas vent mast.

2.6.2.1 Gas Mast

Because of the hazardous nature of vented gas, all gas vents are connected to a gas vent mast. The gas vent mast must be located such that the gas outlet is sufficiently far (>10m or 32.8 ft) from any potential ignition source, working deck, opening to a safe area, or a ventilation intake. To meet this requirement, the gas vent mast will be located on the centerline at amidships and will extend 12.2 m (40 feet) above the outlet of the exhaust. Because the vent mast is so tall, it will likely need to be guyed to the vessel's structure. The structural details of the mast will need to be developed in detailed design.

2.6.2.2 Bleed Vents

Bleed vents will be designed for safe venting and/or purging of gas lines for engine shut down, bunkering, and in response to a gas system alarm.

The gas supply line will be vented by bleed valves in the GSU enclosure. When gas supply to the engine is stopped with the double block-and-bleed valve, the bleed valve will open to vent the pipe between the stop valves. The bleed valve will be connected to the vent pipe from the GSU enclosure to the gas vent mast on the Bridge Deck. The vent piping will run through the ventilated duct up to the Bridge Deck and will be connected to the gas mast.

In addition to the bleed line from the double block-and-bleed valve, there will also be bleed valves on either side of the double block-and-bleed valve that vent the gas supply piping in case of an automatic closure of the master gas valve. These bleed valves will be connected to the vent pipe in the GSU enclosure.

A bleed vent valve in the bunkering line will be located near the tanks. The bunkering bleed vent will be used for purging the bunkering pipe to the vent mast after the completion of the bunkering process.

The storage tanks will be connected to the vent mast by bleed valves located in the tank rooms. These valves will be normally closed, but can be opened to allow purging of the tanks for maintenance.

2.6.2.3 Pressure Relief Valves

There are several pressure relief valves in the system to prevent the pressure from exceeding the maximum allowable pressure in the gas system of 7.5 barg (109 psig). There will be two pressure relief valves on the tanks, several pressure relief valves in the bunkering line, and a pressure relief valve from each GSU. If the pressure relief valves lift, the gas is vented to the gas mast through the various vent piping.

2.6.3 Nitrogen System

Nitrogen is used to purge and inert the bunker pipes and gas supply pipes. To supply the nitrogen, a nitrogen system would need to be installed on the vessel. The nitrogen system would use compressed nitrogen cylinders located in the fixed fire fighting room. This space was selected because it is a well ventilated space that already contains compressed gas cylinders. A pressure regulator would be installed at the nitrogen tank, and nitrogen supply piping would be led to the GSU enclosures, the tank rooms, and the bunker stations. The nitrogen distribution piping would have a maximum working pressure of 10 barg (150 psig).[9]

2.7 Engine Exhaust

Both wet and dry exhaust systems are being considered for this vessel. Both concepts will utilize ventilation fans to purge the exhaust piping in the event of an engine failure to start, and a rupture disk to relieve pressure due to an explosion in the piping.

The dry exhaust system would be a traditional exhaust system with spark arresting silencers fitted in the exhaust casing. The outlet of the exhaust would be at the top of the stacks.

The wet exhaust system would use water jets inside the exhaust piping to cool and condense the exhaust gasses. The wet exhaust outlet would be through the vessel's hull above the waterline. As the wet exhaust system piping requires a downward slope from the water injection point to the vessel's side, a vent pipe would be run from the highest point in the system to weather to prevent any gas buildup.

Both exhaust systems will either be designed with an explosion vent leading to weather, or will be designed such that they will be able to withstand an explosion, as required by the applicable rules.

DNV has preliminarily indicated that they have some concerns that uncombusted gas from an ignition failure could build up in the wet exhaust system and potentially cause an explosion. It will be necessary to further study a wet exhaust concept in order to allay these concerns.

2.8 Weights & Stability

2.8.1 Weight Estimate

A weight estimate has been developed for both the Rolls Royce and Wärtsilä configurations. The estimate was developed to determine change in lightship weight and center of gravity associated with the gas fuel conversion. This information was used for evaluating both the impact on the vessel's stability and structure.

Weights were broken up into either additions or subtractions. Weights associated with systems to be removed were deducted while new system components associated with the gas fuel design were added. Systems that were modified, such as exhaust, were first subtracted and then the weights of the modified system were added. All additions, removals, and modifications to the original design were documented and accounted for in the weight estimate.

[9] DNV stated that to prevent return of flammable gas to a gas safe space, a double block and bleed valve located in a non-hazardous space would be require in the nitrogen system. To address this comment, a double block and bleed valve would need to be installed in the nitrogen supply pipe just outside the fixed fire room. Additionally DNV has stated that closable non-return valves are required in the system. The non-return valves would need to be installed at every connection of the nitrogen system to a pipe or space containing a flammable gas.

When available, exact weights from vendor data were used. For systems and components that had no vendor data available, estimates were made using a combination of materials, arrangement, and routing. A five percent margin was added to both additions and subtractions to account for uncertainty in the weights.

Table 7 lists the revised lightship weight of the vessel with its corresponding longitudinal, transverse, and vertical center of gravity (LCG, TCG, VCG) for the Rolls Royce configuration. Table 8 lists the revised lightship weight of the vessel with its corresponding center of gravity for the Wärtsilä configuration.

Table 7 Rolls Royce System Weight Estimate Summary

Group Description	Weight (LT)	LCG (ft Aft Fr 0)	TCG (ft Stbd CL)	VCG (ft Abv BL)
Original Lightship	3,497.30	-0.38	0.32	28.85
Subtractions	-72.90	6.16	0.33	21.04
Additions	220.83	1.70	0.38	44.04
Revised Lightship	3,645.24	-0.38	0.32	29.93
Margin (5% of Net Weight Change)	7.40	-0.38	0.32	29.93
Lightship (With Margins)	**3,652.63**	**-0.38**	**0.32**	**29.93**
Percent Increase (%)	4.4%			

Table 8 Wärtsilä System Weight Estimate Summary

Group Description	Weight (LT)	LCG (ft Aft Fr 0)	TCG (ft Stbd CL)	VCG (ft Abv BL)
Original Lightship	3,497.3	-0.38	0.32	28.85
Subtractions	-72.9	6.16	0.33	21.04
Additions	216.6	1.67	0.41	44.13
Revised Lightship	3,641.0	-0.39	0.33	29.92
Margin (5% of Net Weight Change)	7.2	-0.39	0.33	29.92
Lightship (With Margins)	**3,648.2**	**-0.39**	**0.33**	**29.92**
Percent Increase (%)	4.3			

2.8.2 Stability

It was necessary to review the stability of the gas fuelled vessel design because the addition of the LNG storage tanks on the Bridge Deck added a substantial amount of weight at a high center of gravity.

The load conditions analyzed in Reference 10 have been modified to suit the operational conditions of the vessel using LNG instead of diesel fuel. The vessel lightship has been modified to account for the weight of the LNG storage tanks, structural modifications, and miscellaneous equipment and systems modifications associated with the conversion to gas fuel. Additionally, because less diesel oil is required when the propulsion engines are gas fueled, the amount of diesel oil in each load condition has been modified to suit the new operations.

The studied load conditions will meet the stability criteria with a reasonable margin. All the load conditions have a conservative amount of free surface and there is no need to add ballast to compensate for the reduced diesel fuel. Only the Rolls Royce option was analyzed but conservative margins in weights and VCGs were used to have equivalent weights to the Wärtsilä option. Because the Wärtsilä engines revert to diesel fuel in the event of a gas supply failure, the Wärtsilä option requires extra diesel fuel to be carried onboard (~ 11.2 m^3 or ~2,950 gal). This extra fuel at the bottom of the vessel would lower the overall VCG which will increase the stability margins. Therefore, the Rolls Royce configuration is the limiting design case for the stability evaluation.

Per Reference 8 the driving stability criteria for the vessel operation in the 4,000 LT to 5,000 LT displacement range is the criteria found in 46CFR-170.173e1. The Maximum VCG data for that criteria found in Reference 8 is used and plotted in Figure 8 along with the modified load conditions.

Initial stability calculations were performed for storage tanks with 10 days of endurance. These calculations demonstrate that the vessel has adequate stability to meet the USCG required criterion. The design has since changed to smaller storage tanks which would reduce the VCG and increase the stability margins.

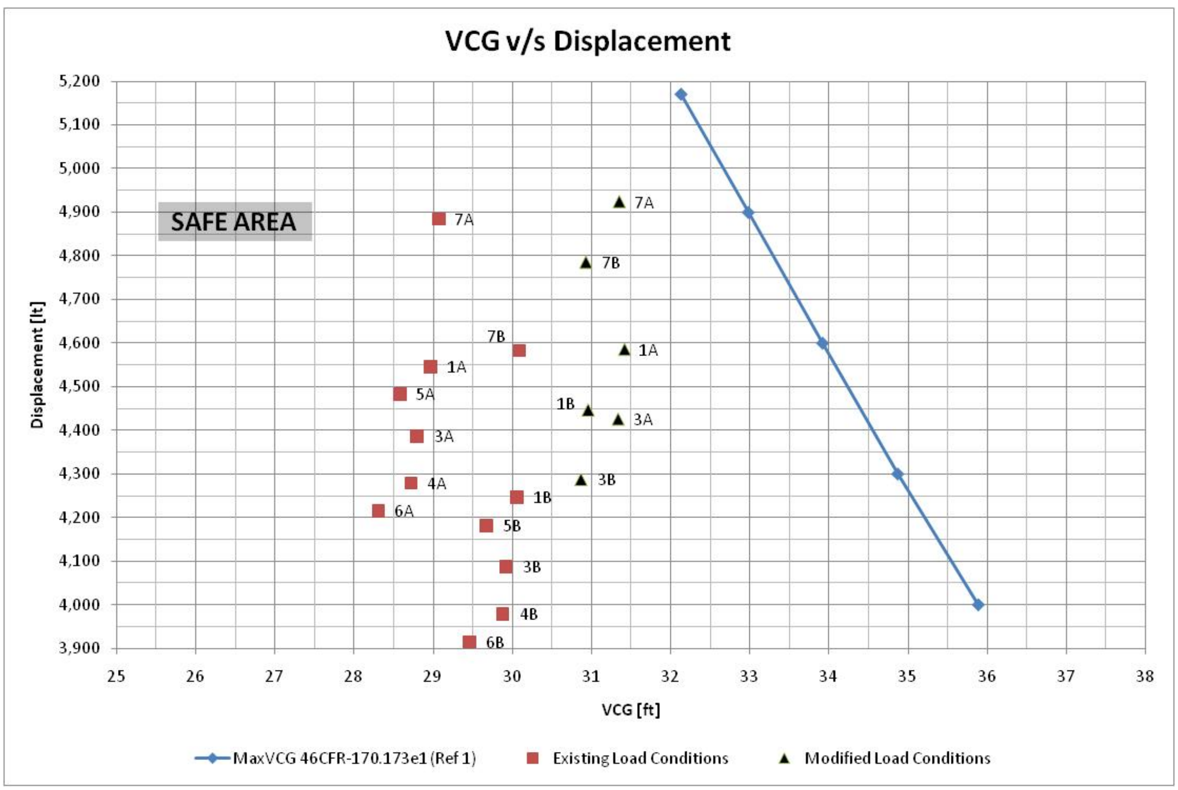

Figure 8 VCG vs Displacement Plot

2.9 Alarm, Monitoring, and Control

An alarm, monitoring, and control system will be provided by the engine and gas system supplier and will be integrated into the vessel's overall alarms, monitoring and control system. The system will provide operational monitoring and controls as well as monitoring and alarms for faults and failures, and control of valves required for automatic shutdown.

2.9.1 Detectors

In order to comply with the regulations, a number of specific detectors and sensors are required for gas fuelled vessels. The following detectors and sensors will be fitted.

Table 9 Detectors and Sensors

Locations	Qty	Location
Tank Room (each)	1	Smoke Detector
	1	Heat Detector
	1	Bilge Low Temperature Alarm
	1	Bilge High Level Alarm
	2	Gas Detectors
Tanks (each)	1	Pressure Sensor
	1	Level Indicator
	1	High Level Alarm
Ventilation Duct (each)	3	Gas Detectors
Engine Room (each)	2	Gas Detectors
	1	Smoke Detector
	1	Heat Detector
GSU Enclosure (each)	1	Gas Detector

In addition to the sensors and alarms listed in Table 9, the ventilated ducts around gas piping in each machinery space will be equipped with an alarm for ventilation failure.

2.9.2 Faults and Effects

A list of faults and effects has been compiled from both the DNV rules (Reference 1) and IMO Resolution MSC.285 (86) (Reference 2), and is included in Appendix A. This list is intended to show how the gas monitoring and alarm system provides control input to the engines and various valves in the gas system.

2.10 Fire Protection & Suppression

In addition to the typical fire protections and suppression systems required for a diesel fuelled passenger vessel, there are several specific fire detection and suppression systems required for gas fuelled vessels. These systems include a water spray system to protect the storage tanks, fixed fire systems to protect the bunkering stations, and additional structural fire protection.

2.10.1 Water Spray System

The water spray system has been designed to meet all of the applicable rules in References 1 and 2. The water spray system will be installed above the LNG storage tanks for cooling and fire prevention. The water spray system will be a branch off the deluge sprinkler system that serves the vehicle decks of the vessel.[10]

A separate suction from the seachest to a dedicated sprinkler pump is included in the current vessel design. The pump will feed the sprinkler manifold where a separate branch will be run to each zone. The tank area on the Bridge Deck will be served by an independent branch. The valve(s) in the manifold will be motor operated and the pump will be configured for remote start.

The sprinkler pump has been verified to maintain the necessary 2,400 L/min (634 gal/min) from the engine room to the Bridge Deck. This is based on full tank deck coverage at the required 10 L/min/m^2 (0.245 gpm/ft^2) horizontal and 4 L/min/m^2 (0.098 gpm/ft^2) vertical flow rates. An emergency crossover to the fire main system will also be provided.

2.10.2 Fixed Fire Protection

Each bunkering station will be equipped with a dry chemical fire extinguishing system. Each system will be self contained. The dry chemical will be stored under the vehicle ramp adjacent to the bunkering station. Each system will be sized to provide the required 3.5 kg/s for 45 seconds.

2.10.3 Structural Fire Protection

Additional Structural Fire Protection (SFP) will be required in the vicinity of the LNG storage tanks. The Bridge Deck in way of the storage tanks will need to be insulated with A-60 structural fire protection. Additionally both exhaust casings will need to be insulated with A-60 structural fire protection on the inboard side facing the storage tanks.

2.11 Auxiliary Generators

The existing vessel design utilizes three auxiliary diesel generators to provide the ship service power while the vessel is underway and at the dock. The generators are sized such that two generators can provide the design load and the third generator is in standby. At the time of the publication of this report, the electrical load analysis was not yet completed for the vessel. However, it was estimated that the generators will each be sized for 300 kW (402 HP) each with a maximum design load of 450 kW (603 HP).

In this study three options were considered for generation of electrical power. These options were

1) To retain the existing design with three 300 kW (402 HP) diesel generators,

[10] USCG has stated that the waterspray system must also cover any normally occupied spaces that face the storage tank. To address this requirement, the waterspray system would need to be extended to cover the two pilothouses.

2) To replace the diesel generators with three 300 kW (402 HP) gas fueled generators, or
3) To replace two of the diesel generators with two 300 kW (402 HP) shaft generators driven by the main engines and retain one diesel generator as the standby and in port generator.

The first option of retaining the three diesel generators will not result in any changes to the vessel design.

At the time of publication of this report, the authors are unaware of any inherently safe gas marine generators in the 300 kW (402 HP) size range. As was discussed in the selection of the propulsion engines, inherently safe engines are a requirement of this design. As a result of the lack of inherently safe generators, this option was not pursued further. It is worth noting that Mitsubishi does make a marine gas generator set of this size. However, it is not inherently gas safe and was therefore not considered.

The third option, using shaft generators driven by the main engines, was also considered. In the case of the Rolls Royce package the generators would need to be driven by a Power Take Off (PTO) from the front of the engine because the existing gears do not have a PTO. In the Wärtsilä package, the generators could be driven off either a front engine PTO or a gear PTO because new reduction gears are already required for the propulsion engines. Because the generators are driven by variable speed propulsion engines, the generators would need to be a variable speed generator. Power electronics would need to be used to convert the power to clean 60 Hz power to feed the main switchboard.

Both Wärtsilä and Rolls Royce have indicated that they have a generator system that could be used in this application. However, neither vendor was able to provide sufficient technical details of the generators and electronics within the timeframe required to be included in this study. There is a possibility that a significant fuel cost savings could be achieved using shaft generators, however this will need to be investigated further in a separate study, if desired.

Using shaft generators off the propulsion engines will of course increase the gas fuel consumption. This would result in either a reduction of the endurance of the vessel or an increase in required tank size to meet the 10 days endurance. It is estimated that the fuel consumption would be increased by 10-15% depending on the efficiency of the generators and electronics.

Section 3 Impacts to Existing Design

In addition to the installation of the new equipment required for fuelling the vessel with LNG, there are several systems in the current vessel design that will require modification to support the new equipment. Additionally some modification to the existing vessel design will be necessary to comply with rules that are applicable for gas fuelled vessel. In general only substantial system modifications that have been identified are discussed in this section. Additional modifications may be necessary and will be further identified in future phases of development.

3.1 Machinery Arrangement

The machinery arrangement for both the Rolls Royce and Wärtsilä systems were kept as similar as possible. In order to accommodate the new machinery for the gas fuel, the arrangement of some equipment in the existing vessel design will be impacted. The affected systems for the proposed design are outlined as follows.

- Both main engine foundations will require redesign to maintain alignment of the engine output shaft and the input shaft on reduction gear.
- Exhaust piping will need to be rerouted on the hold level. If a traditional exhaust is used, deck penetrations and silencer placement will be kept as similar as possible to the original piping runs, but may be impacted slightly because of varying pipe sizes. If a wet exhaust is used, exhaust pipe routing in the engine room may affect pipes and wiring in the overhead and may impact the locations of some equipment.
- The fire pump suction and discharge manifolds in both engine rooms will need to be relocated slightly inboard and towards amidships.
- The fire pump suction strainer and the fire & sprinkler pump in both engine rooms will need to be relocated towards the ends of the vessel by a few feet to allow room for the GSU enclosure.
- Several tank access manholes will need to be relocated to avoid being blocked by new equipment.

3.2 Compressed Air System

The compressed air system as currently designed is for 14 barg (200 psig) starting air with the starting air receivers at 16 barg (230 psig). Both the Bergen C26:33 L9PG engine and the Wärtsilä 6LDF34 engine require the starting air to be supplied at 30 barg (435 psig). This will require different air compressors that are capable of supplying air at 31 barg (450 psig). Additionally, the starting air receivers and piping will need to be upgraded to the higher working pressure of 31 barg (450 psig). The capacity of the receivers will have to be evaluated to ensure that the receiver volume provides a sufficient number of starts to meet the applicable regulations.

3.3 Sprinkler and Firemain System

A new branch off the sprinkler system will need to be installed to serve the water spray system for the storage tanks. The sprinkler pump in the existing design is of sufficient size to meet the required sprinkler service. Some sprinkler system valves may need to be replaced with remotely operated valves so that the LNG storage tank water spray system can be automatically started.

The firemain system fire station locations will require evaluation to ensure there is adequate stations and isolation near the LNG storage tank.

3.4 Fuel Oil Storage and Transfer

The fuel oil storage, transfer and supply systems will need to be redesigned. The use of the single fuel engine eliminates all propulsion uses of diesel fuel while the duel fuel engine only requires a small amount of pilot fuel for gas operations. Unless the optional installation of PTO driven generators is implemented, diesel fuel will still be required to operate the ship service generators. For electrical generation a total of 17.4 m^3 (4,600 gallons) of fuel storage is required to accommodate 10 days of diesel fuel endurance. Pilot fuel for the Wärtsilä duel fuel engine will add 2.6 m^3 (700 gallons) to the 10 day endurance requirement. The two diesel day tanks in the existing design have a 95% capacity of 22.9 m^3 (6,048 gallons). The two existing day tanks have enough capacity to support 10 days of diesel fuel endurance. The existing transfer piping and pumps, purification system, and supply piping will need to be resized based on the final propulsion engine and generator selections.

The existing design had two additional diesel fuel storage tanks, the port tank is sized at 151.8 m^3 (40,100 gallons) and the starboard tank is sized at 87 m^3 (23,000 gallons). If additional diesel fuel capacity is desired these tanks could be segregated to store as much fuel as desired. If these existing tanks are not used, removal of the unused tank structure should be investigated to reduce construction cost. Removal of tank structure was not investigated in this report.

3.5 Hot Water Heat System

The glycol system used to vaporize and heat the LNG will be served from the existing designs hot water heat system. The glycol system heat exchangers will be served by a new branch of the hot water system that will originate at the hot water manifold in the machinery space and will be routed up the exhaust casing to the upper deck.

In the current vessel design, the hot water system provides the heat for the HVAC, hot domestic water, and various other heating demands. The current estimated design demand on the hot water system at the design condition as given in Reference 9 is 1,235 kW. The LNG vaporizer and heater will require approximately an additional 270 kW for the Rolls Royce system and 476 kW for the Wärtsilä system at rated engine power. It has been assumed that the vaporization energy for the gas system will vary directly with the engine output but the hot water heating demand will be constant.

The current hot water system utilizes waste heat from the high temperature jacket water circuit of the main engines. The waste heat is supplemented by an oil fired water heater and electric water heater. With the additional demand of the gas system, the engines do not generate enough waste heat in the high temperature cooling circuits to meet the all the demands at the design condition. The oil fired hot water heater will need to be used at times of peak heating demand or low engine loads to supplement the waste heat system. Table 10 tabulates the available waste heat from the high temperature jacket water circuits and the hot water demands.

Table 10 Waste Heat

	Total Power (kW)	Total Heat Rejection (kW)	Hot Water Heat Demands (kW)	Gas System (kW)	Heat surplus (+) / Deficit (-) (kW)
Bergen C26:33L9PG					
MCR	4400	1247	-1235	-270	-258
Transit	3441	976	-1235	-211	-471
Docked	379	107	-1235	-23	-1151
Wärtsilä 34DF (Derated to 2300 kW)					
MCR	4600	1346	-1235	-490	-379
Transit	3441	1007	-1235	-366	-594
Docked	379	111	-1235	-40	-1164

Wärtsilä has indicated that the glycol system can utilize waste heat from the low temperature (LT) cooling circuit. It may also be possible to utilize the LT circuit in the Rolls Royce system as well. Utilizing the LT circuit waste heat would reduce the deficit of waste heat during peak heating demand or low engine load. This would reduce the amount of heat required from the oil fired water heater or electric water heater. Utilizing the waste heat from the LT circuit should be further investigated in the detailed design once more specific engine and gas system performance information is available from the manufacturers.

In order for the existing hot water heat system to have the increased capacity to serve the glycol system on the Bridge Deck, some modifications will be necessary. The hot water heat system in the current design has a design temperature of 82°C (180°F) and a design flow rate of 104 m^3/hr (460 GPM). The system is configured with parallel primary and standby pumps each sized for 104 m^3/hr (460 GPM). It has been calculated that an additional 43 m^3/hr (190 GPM) of hot water will be required to serve the gas system for a total of 148 m^3/hr (650 GPM). We recommend that the two 104 m^3/hr (460 GPM) pumps be replaced with three 74 m^3/hr (325 GPM) pumps configured in parallel with one pump as a standby. In addition to changing the pumps, the waste heat recovery heat exchangers, oil heater, and electric heater will need to be resized for the increased flow rate and heat demands. A new hot water supply and return branch to the Bridge Deck will also need to be added from the supply and return manifolds in the engine room and the main system piping in the engine room will need to be increased from 5” to 6” diameter pipe.

3.6 Structure

The LNG storage tanks will be free standing tanks that will be mounted to the vessel through two main cradles that support the tanks at approximately the quarter points of each tank. Figure 9 depicts a typical LNG storage tank being lifted into a vessel. The cradles are welded to the outer shell of the tank. Because of the cryogenic nature of LNG, the tanks will experience thermal expansion and contraction. As a result, only one of the cradles is welded to the deck of the vessel. The other cradle is able to slide slightly to compensate for thermal expansion and contraction.

Figure 9 Typical LNG Storage Tank

The Bridge Deck and supporting structure was reviewed to determine the extent of modification required to support the LNG storage tanks. Both the single tank configuration and a double tank configuration were considered. Both configurations will require structural modifications however the extent of modifications for the single tank arrangement is greater. Figure 10 and Figure 11 depict the arrangement of tanks on the Bridge Deck structure.

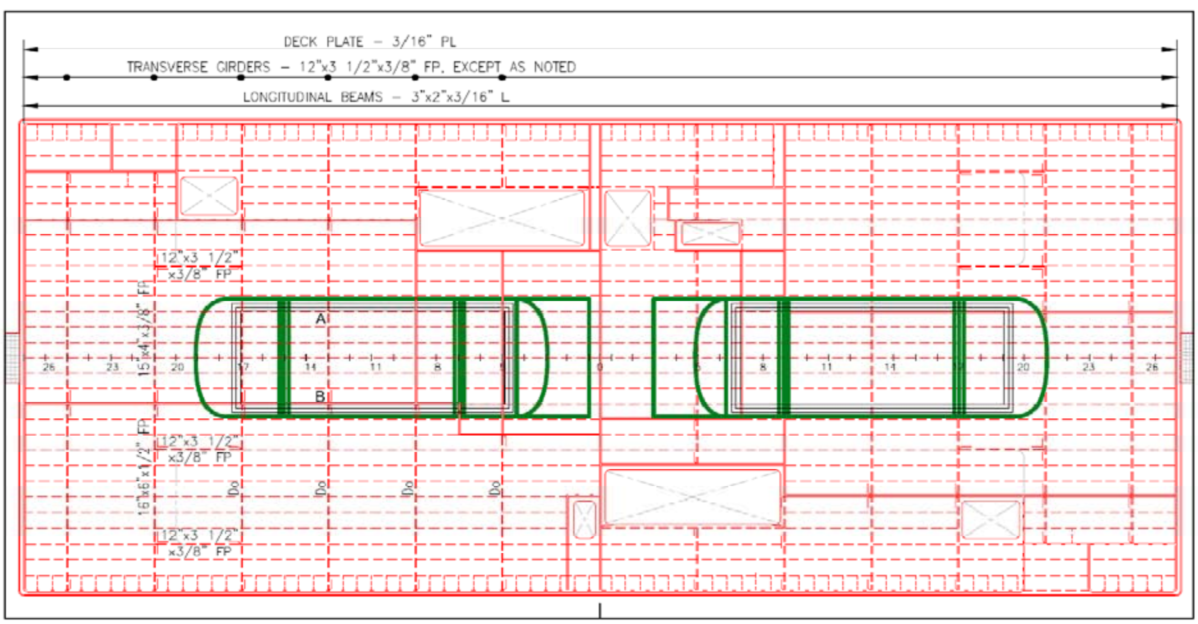

Figure 10 Bridge Deck Structural Arrangement of Two Tanks

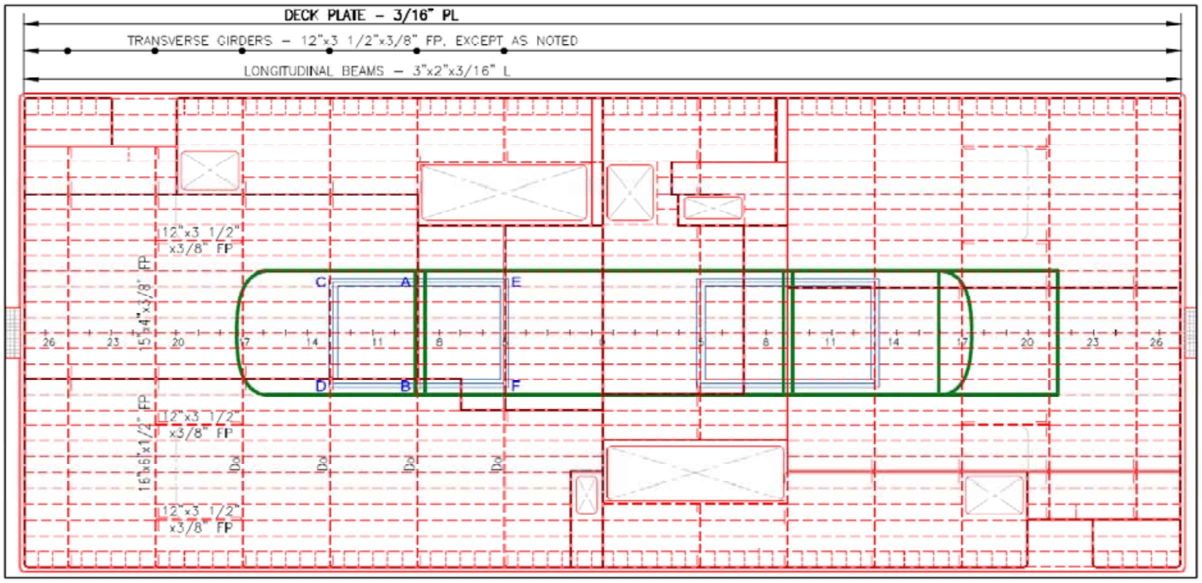

Figure 11 Bridge Deck Structural Arrangement of Single Tank

In order for the bridge deck to be able to support the loads imposed by the LNG tanks, the deck will need to be reinforced. It is recommended to build a skid made out of stiff I-beams (e.g. W10x100) to support the legs of the tanks and better distribute the loads to the bridge structure. The single tank configuration will require more reinforcement of the deck structure than the two tank configuration since the weight of the single tank will be transferred to the deck over a smaller area. Stanchions will have to be placed under the existing transverse girders of the deck and if the single tank option is adopted then the bulkheads in the way of the tank foundation will have to be redesigned for those loads using thicker plates and larger stiffeners. Additionally, the deck below (Sun Deck) needs to be analyzed to see if reinforcement is needed in order to support the loads of the stanchions above. Once a specific tank has been selected, a detailed design of the tank foundations will need to be done.

3.7 Doors and Openings

Openings to non hazardous spaces may not be located in a hazardous area unless they are fitted with an air lock. This may require that the spaces with access opening on the inboard side of the casings from the Bridge Deck may need to be relocated or fitted with an airlock. The extent of the effected openings will be dependent on the details of the arrangement of the gas piping system on the Bridge Deck. However, it is anticipated that no more than four opening will be affected.

Section 4 Emissions

The engine emissions were analyzed to compare the relative air emissions of the existing diesel design and the Wärtsilä and Rolls Royce gas fuelled vessel designs. The purpose of this analysis was to help quantify the reduction in air emissions by converting the diesel fueled engines to gas fuel. Emissions from the ships service diesel generators were not considered for this analysis.

4.1 Route

The route chosen for the emissions analysis was not based on an actual route but rather on a route representing an average route. This operating profile was the same as the one used during the propulsion study for the 144-Car Ferry, Reference 3. Table 11 shows the operating profile assumed in the analysis.

Table 11 Operating Profile

Power Requirements and Annual Operating Hours							
Condition	Engine Power	No Engines	Total Power		Hours	Operating	
	kW		kW	HP		kWh/year	HPh/year
Transit	1,721	2	3,441	4,614	3,000	10,323,000	13,842,000
Maneuvering	391	2	781	1,047	1,000	781,000	1,047,000
Docked	190	2	379	508	2,000	758,000	1,016,000
Total					6,000	11,862,000	15,905,000

4.2 Methodology

The emissions for each of the engines was computed for a year based on the operating profile, see Table 11. The required engine power was converted to a percentage of MCR and the corresponding specific emissions in grams/kilowatt-hour were determined from vendor data for each of the components of the exhaust gas. The specific emissions were multiplied by the total yearly kilowatt-hours for each operating condition then summed to determine to component emissions for the year.

Sulfur oxide (SO_x) emissions are only dependant on the sulfur content of the diesel fuel and the overall engine diesel consumption. An Ultra Low Sulfur Diesel (ULSD) fuel with a sulfur content of 15 parts per million was assumed for this analysis. SO_x emissions are converted and reported as SO2.

4.3 Discussion

The results of the analysis are summarized the Table 12 and in Figure 12 through Figure 17.

Nitrogen oxides (NO_x) are generated when nitrogen reacts with oxygen at high temperatures and pressures. In general gas engines run at lower temperatures and pressures and lower NO_x emissions would be expected.

Particulate matter (PM) and Sulfur dioxide (SO_2) emissions vary linearly with the quantity of diesel used. The EMD engine uses the most diesel followed by the Wärtsilä dual fuel engine and the Bergen uses no diesel. The emissions results agree with this.

Carbon monoxide (CO) is a product of incomplete fuel ignition. The higher CO emissions in the gas engines show less efficient combustion.

Carbon dioxide (CO_2) is a result of combustion and is proportional to the amount of energy consumed. Specific CO_2 emissions were not available for the EMD engine and are not shown in the chart or graphs. It is expected that the CO_2 emissions for EMD would be similar to although slightly higher than the gas engines.

Methane is generated in gas fuelled engine emissions when methane is left unburned in the cylinder after ignition. This unburned gas is expelled with the exhaust and contributes to the engine emissions. The diesel engines also produce a small amount of methane as a combustion byproduct. At the time of this report the specific methane emissions for the Wärtsilä engine were not available. However Wärtsilä indicated that the total hydrocarbon emissions are less than 6 g/kW-hr and that non methane hydrocarbon emissions were 1 g/kW-hr. Based on this information, the methane emissions for the Wärtsilä engine were assumed to be 5 g/kW-hr.

Non methane hydrocarbons (NMHC) are a result of unburned hydrocarbons in the exhaust gas.

The Global Warming Potential of the three engines over their lifecycle was not calculated in this report. The Global Warming Potential is a relative measure of how much heat a greenhouse gas traps in the atmosphere. If the CO_2 emissions are lower for the gas engines the methane emissions will offset them somewhat. Methane is a more powerful global warming gas than CO_2 by roughly 25 times over a 100 year period. It is expected that switching to gas engines will not have a significant impact one way or another in the vessel's overall Global Warming Potential.

Table 12 Emissions Comparison

Emission	Wärtsilä	Rolls Royce	EMD
NOx (ton)	24.7	15.7	89.0
SO2 (ton)	0.01	none	0.77
CO (ton)	41.3	20.0	3.4
CO2 (ton)	6,415	6,203	7,980
PM (ton)	1.13	none	2.33
Methane (ton)	65.38	59.2	0.32
NMHC (ton)	1,708	not provided	3.71

*ton = 2,0000 lbs

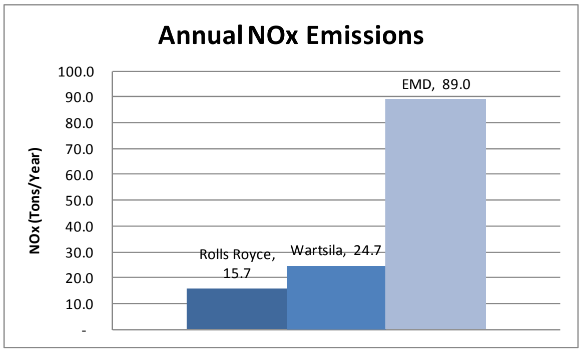

Figure 12 Annual NOx Emissions

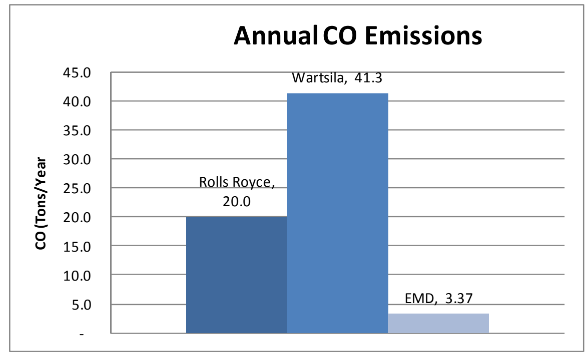

Figure 13Annual CO Emissions

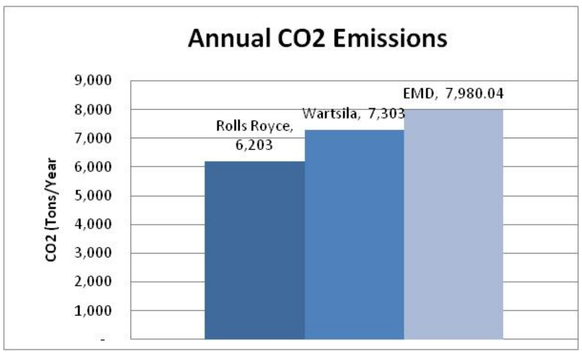

Figure 14 Annual CO2 Emissions

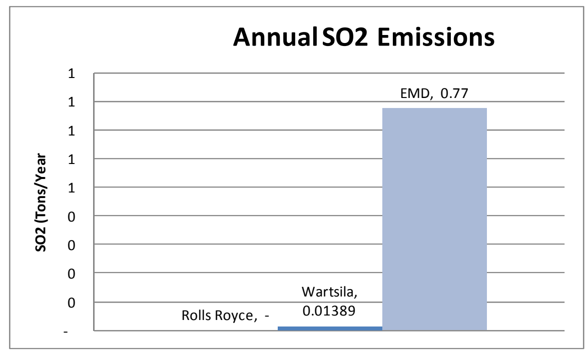

Figure 15 Annual SO2 Emissions

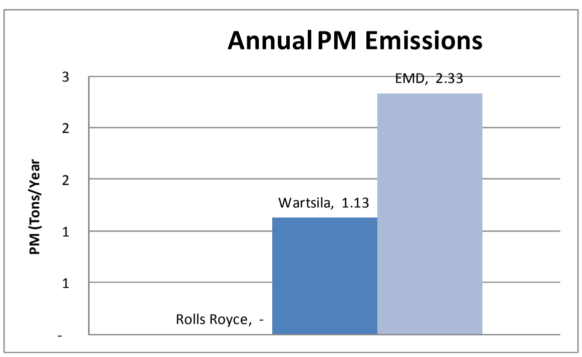

Figure 16 Annual PM Emissions

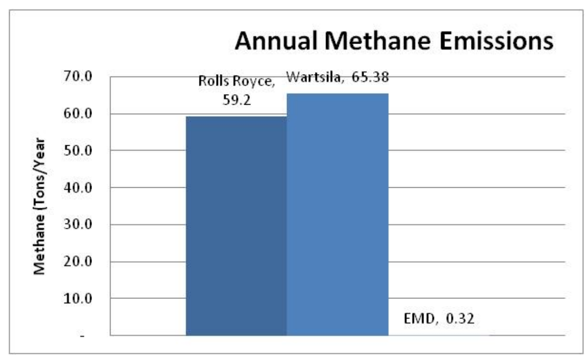

Figure 17 Annual Methane Emissions

*Ton = 2,000 lbs

Section 5 Conclusions

This report has discussed the design of both a single fuel gas system provided by Rolls Royce and a dual fuel gas system provided by Wärtsilä. From a technical standpoint, both systems appear to be feasible to implement in the 144-Car Ferry design without any high risk impacts to the existing vessel design.

There are however, some significant changes to the design that will need to be considered. The detailed design and installation of the engines, engine foundations, gears, gas system, gas piping and gas system ventilation, and ancillary equipment will require effort. Additionally, the structure of the Bridge Deck will need to be reviewed and reinforced. The locations of the ventilation intakes and exhausts and openings to spaces in the casing will need to be reviewed and possibly modified. Several systems will require modifications including the control system, sprinkler system, hot water system, ventilation systems, and compressed air system. None of these additions or modifications, however, presents a substantial risk to the feasibility of the design.

The main focus of this study was the use of gas fuelled engines for propulsion, however ship service power generation was also considered. Gas fuelled generators were not considered due to a lack of availability. Depending on the timeframe in which additional development of the gas fuelled ferries is done, it may be worth reconsidering gas fueled generators if additional equipment becomes available. Shaft generators were considered and this concept has merit but unfortunately not enough detailed information was available to develop the concept. It is recommended that shaft generators be revisited as an option for ship service power once more information is available.

An analysis of the emissions was conducted for the two gas engines and the currently designed diesel engine. Methane emissions are increased by switching to gas. Overall CO_2 equivalent emissions are not expected to be reduced considerably. The Global Warming Potential of the ship is not expected to be impacted significantly by switching to gas engines. Significant reductions in SO_x, NO_x, and PM are achieved by switching from diesel to natural gas. These three gasses contribute to local air pollution and reducing them significantly should be a benefit to local air quality.

Neither the Wärtsilä system nor the Rolls Royce system has clear technical superiority. Both systems have some advantages and disadvantages. The Rolls Royce system has slightly better fuel consumption and engine response. The Wärtsilä system has more flexibility because it is dual fuel and it only requires a single storage tank. Neither system has any deficiency that makes it unsuitable for application in the 144-Car Ferry, and selection will come down to a combination of owner preference of operating characteristics, emissions, and capital and lifecycle cost (Costs are discussed separately in The Glosten Associates, Inc., Report *144-Car Ferry LNG Fuel Conversion Feasibility Study: Life Cycle Cost, reference 16*).

Appendix A Faults and Effects Table

Fault/Action	Alarms	Response	DNV Rule	IMO Resolution MSC.285(86)	Notes
Gas detection in Tank Room above 20% LEL	yes	none	6/B401	Table 1 Chap V	
Gas detection on 2nd detector in Tank Room above 20% LEL	yes	Automatic shutdown of main tank valve	6/B401		
Gas detection on 2 detectors in Tank Room above 40% LEL	yes	Automatic shutdown of main tank valve		Table 1 Chap V	
Fire detection in tank room	yes	Automatic shutdown of main tank valve, ventilation of space shall stop, fire damper shall close	6/B401	Table 1 Chap V	
Bilge well high level in tank room	yes	none	6/B401	Table 1 Chap V	
Bilge well low temperature in tank room	yes	Automatic shutdown of tank valve	6/B401	Table 1 Chap V	
Gas detection in duct between tank and engine room above 20% LEL	yes	none	6/B401	Table 1 Chap V	
Gas detection on second detector in duct between tank and engine room above 20% LEL	yes	Automatic shutdown of master gas valve to effected pipe	6/B401		
		Double block and bleed valve to close and vent	3/E104		
		Automatic open vent valve to gas supply between master gas valve and double block & bleed valve.	3/E105		
Gas detection on 2 detectors in duct between tank and engine room above 40% LEL	yes	Automatic shutdown of master gas valve to mach. space containing gas engine		Table 1 Chap V	
		Double block and bleed valve to close and vent		5.6.3	
		Automatic open vent valve downstream of double block & bleed valve.		5.6.4	
Gas detection in duct inside engine room above 30% LEL	yes	none	6/B401	Table 1 Chap V	
Gas detection in duct inside engine room above 60% LEL	yes	Automatic shutdown of master gas valve.	6/B401		
		Double block and bleed valve to close and vent	3/E104		
		Automatic open vent valve to gas supply between master gas valve and double block & bleed valve.	3/E105		
Gas detection on 2 detectors in duct inside engine room above 40% LEL	yes	Automatic shutdown of master gas valve.		Table 1 Chap V	
		close and vent		5.6.3	
		Automatic open vent valve downstream of double block & bleed valve.		5.6.4	
Gas detection in engine room above 20% LEL	yes	none	6/B401	Table 1 Chap V	Only required if duct intakes air from engine room
Gas detection on second detector in engine room above 20% LEL	yes	Automatic shutdown of master gas valve.	6/B401		Only required if duct intakes air from engine
		Double block and bleed valve to close and vent	3/E104		
		Automatic open vent valve to gas supply between master gas valve and double block & bleed valve.	3/E105		

Fault/Action	Alarms	Response	DNV Rule	IMO Resolution MSC.285(86)	Notes
Gas detection on 2 detectors in engine room above 40% LEL	yes	Automatic shutdown of master gas valve.		Table 1 Chap V	Only required if duct intakes air from engine
		Double block and bleed valve to close and vent		5.6.3	
		Automatic open vent valve downstream of double block & bleed valve.		5.6.4	
Loss of ventilation in duct between tank and engine Room	yes	Automatic shutdown of master gas valve.	6/B401		Master Gas Valve is not shut down for single fuel engine
Loss of ventilation in duct between tank and engine Room	yes	Automatic shutdown of master gas valve.		Table 1 Chap V	Master Gas Valve is not shut down for single fuel engine
Fire detection in engine room	yes	Automatic shutdown of master gas valve.	6/B401	Table 1 Chap V	
		Double block and bleed valve to close and vent	3/E104	5.6.3	
		Automatic open vent valve to gas supply between master gas valve and double block & bleed valve.	3/E105		
		Automatic open vent valve downstream of double block & bleed valve.		5.6.4	
Abnormal gas pressure in supply pipe	yes	none	6/B401	Table 1 Chap V	shut down for single fuel engine
Failure of valve control actuating medium	yes	Close double block and bleed valve	6/B401	Table 1 Chap V	Time delayed as found necessary
Automatic shutdown of engine (engine failure)	yes	Close double block and bleed valve	6/B401	Table 1 Chap V	
Emergency shutdown of engine manually released	yes	Automatic shutdown of master gas valve.	6/B401	Table 1 Chap V	
		Double block and bleed valve to close and vent	3/E104	5.6.3	
		Automatic open vent valve to gas supply between master gas valve and double block & bleed valve.	3/E105		
		Automatic open vent valve downstream of double block & bleed valve.		5.6.4	
Any loss of required ventilation capacity	yes	none	6/B501	2.10.1.3	Alarm shall sound at permanently manned location
Loss of ventilation in duct around bunkering line	yes	none	6/B502	2.9.2.3	Alarm shall sound at bunkering control location
Full stop of ventilation in an engine room	yes	Engine in room with ventilation loss shall be shut down	6/B503	5.6.7	Engine only to be shut down if 40% propulsion power is available from other engine
Gas detection in bunkering line ventilation	yes	none	6/C105	2.9.2.4	Audible and Visual alarm at the bunker station

Appendix B DNV Classification Comments

DET NORSKE VERITAS

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Your ref.:	Our ref.:	Date:
	NACNO385/GRIMS/29 Other-J-11524	2011-06-06

WSF LNG Ferry Concept Review

Reference is made to your letter dated 2011-05-18. The following documents are reviewed 2011-06-06 and given the status as shown:

Drawing No.	Rev.	DNV No.	Title	Code	Status
11030.01	16 May 2011	2081	Regulatory Review of Concept, including appendices A, B and C		Examined w/comm
11030-500-01	P1	2082	Piping Arrangement -Concept Regulatory Review (9 sheets)		Examined
		2083	General arrangement model -Concept Regulatory Review		Examined

	Drawing No. 11030.01/16 May 2011, "Regulatory Review of Concept, including appendices A, B and C" is examined for compliance with DNV Rules Pt.6 Ch.13, with the following comments:	**Status**
146	Refer to Appendix A, index #32: Please note that if the vacuum insulated pipes have flanges inside the ventilated duct, the flanges will need to be protected to avoid risk of liquid spill onto normal ship steel. If the piping system however has no flanges inside the ventilated outer duct, the vacuum insulation is accepted as a means to protect the duct from spill.	For Inf.
147	Refer to Appendix A, index #51: We can accept the location of the bunkering pipes less than 760 mm from the ship side as described in the documentation.	For Inf.
148	Refer to Appendix A, index #55: Please be informed that knock out drums are normally not needed for natural gas systems.	For Inf.
149	Refer to Appendix A, index #82: We note that the ventilated duct for the gas pipes inside the engine room are combined with the duct outside of the engine	For Inf.

room. Since the ventilation air for the double duct in the engine room is taken from the engine room, it must be assured that a gas leakage in the duct outside the engine room can not flow to the engine room. Such a common ventilated duct can be accepted for the engine room gas pipes and for the part of the gas supply pipes between the tank room and the engine room, but this duct should not also contain bunkering pipes.

150 Refer to Appendix A, index #137: Please be informed that the requirement for redundant ventilation fans in Rules Pt.6 Ch.13 Sec.3 I 403 should not be made applicable for inherently safe engine rooms. It is however applicable to the ventilation system for the double gas duct in such an engine room. For Inf.

151 Refer to Appendix A, index #144/145: Please note that in addition to the requirements in Rules Pt.6 Ch.13 Sec.3 J100 for the nitrogen installation spaces, there are also requirements to the nitrogen system, if the nitrogen installation is in a gas safe space: For Inf.

1. To prevent the return of flammable gas to any gas safe spaces, the inert gas supply line shall be fitted with two shutoff valves in series with a venting valve in between (double block and bleed valves). In addition a closable non-return valve shall be installed between the double block and bleed arrangement and the cargo tank.
These valves shall be located outside non-hazardous spaces and must function under all normal conditions of trim, list and motion of the ship.
The following conditions apply:
a) The operation of the valves shall be automatically executed.
Signals for opening and closing shall be taken from the process directly, e.g. inert gas flow or differential pressure.
b) An alarm for faulty operation of the valves shall be provided.

2. Where the connections to the gas piping systems are non-permanent, two non-return valves may substitute the non-return devices required above.

152 Refer to Appendix A, index #153: The arrangement of the bunkering station as described and shown in documentation is found to be acceptable. For Inf.

153 Refer to Appendix A, index #242: In the next rule revision we will include the option for engine manufacturers to document that starting, stopping and low load operation on gas is possible. For Inf.

154 Refer to Appendix A, index #172: Please be informed that the dry powder extinguishers outside engine rooms are not required for natural gas fuelled ships, as the natural gas is lighter than air. For Inf.

155 Refer to Appendix C, first item on second page: Please be informed that DNV does not require shut down actions connected to the gas detection in inherently safe engine rooms, only alarm. For Inf.

Status

Drawing No. 11030-500-01/P1, "Piping Arrangement -Concept Regulatory Review (9 sheets)" is examined for compliance with DNV Rules Pt.6 Ch.13

Drawing No. (empty), "General arrangement model-Concept Regulatory Review" is examined for compliance with Rules Pt.6 Ch.13 **Status**

Yours faithfully
for DET NORSKE VERITAS AS

Øivin Lorentzen
Head of Section
Cargo Handling and Piping Systems

Torill Grimstad Osberg
Contact Person

Copy To: Tony Teo; Nick Roper

Appendix C USCG Regulatory Comments

U.S. Department of Homeland Security
United States Coast Guard

Commandant
United States Coast Guard

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2011-2906
16715
July 1, 2011

Captain George A. Capacci
Deputy Chief, Operations and Construction
Washington State Ferries
2901 3rd Avenue, Suite 500
Seattle, WA 98121-3014

Dear Mr. Capacci:

Thank you for your June 2, 2011 letter concerning the use of Liquefied Natural Gas (LNG) as a propulsion fuel on passenger ferries in Puget Sound. In conjunction with your letter, we received a package from Glosten Associates, dated May 16, 2011, presenting a design concept for an LNG fueled propulsion system on the new 144-car ferry class you describe in your letter. Having reviewed and discussed the proposal with Glosten Associates, we have prepared the following response which will serve as a regulatory design basis should you choose to move forward with the LNG-fueled 144-car ferry project.

Once an application for inspection is filed with the Officer in Charge, Marine Inspection (OCMI), all required plans should be forwarded to the Marine Safety Center (MSC) for plan review. The MSC will use this regulatory design basis letter and applicable regulations and standards to complete plan review. Please note that due to your proposed use of LNG fueled propulsion systems, MSC may identify additional detailed design requirements in areas not addressed in this regulatory design basis agreement during the course of plan review. As always, the OCMI may impose additional requirements, should inspection during construction reveal the need for further safety measures or changes in construction or arrangement.

The 144-car ferry class vessels will be certificated under 46 CFR Subchapter H and must meet the applicable requirements in 46 CFR Subchapters F and J. However, as these subchapters do not address LNG fueled propulsion systems, from Glosten Associates' submission, we understand the proposed design would instead comply with IMO Resolution MSC.285(86), Interim Guidelines on Safety for Natural Gas-Fuelled Engine Installations in Ships. Glosten Associates requested clarification from the Coast Guard on how the guidelines will be applied for this application, with special emphasis on major areas listed in the executive summary of their submission.

We accept the use of the IMO Interim Guidelines subject to the additional requirements in this letter, which serves as the design basis for the LNG-fueled 144-car ferries. For any issues not specifically addressed by the IMO Interim Guidelines as modified by this letter, 46 CFR Subchapters F, H and J will apply. Clarification on the major areas Glosten Associates listed in the executive summary of their submission is provided below in the context of the IMO Interim Guidelines. The definition of "open gas sources" is addressed in item 1; the location, fire protection and isolation of bunkering stations are addressed in items 4, 6 and 11; the location of ventilation supply for gas supply piping ducts is addressed in item 7; and ventilation of the tank room is addressed in item 9.

Design Basis

The design of the gas-fueled propulsion system shall meet the requirements of IMO Resolution MSC.285(86) (Jun 1, 2009), except as modified below. For ease of reference, each comment is preceded by the applicable cite from IMO Resolution MSC.285(86).

1. **Section 2.1.3** For the purposes of Section 2.1.3, the term "open gas sources" has the same meaning as "source of release" defined in paragraph 1.3.32: "Source of release means any valve, detachable pipe joint, pipe packing, compressor or pump seal in the gas fuel system." This would not apply to double-wall piping systems that meet the arrangements in 2.7.1.1 or 2.9.3.1.

2. **Section 2.2** In addition to IMO Resolution MSC.285(86) section 2.2, piping for natural gas fuel must meet requirements in 46 CFR 56.60. Materials for low temperature piping (below 0 degrees F) must meet the requirements of 46 CFR 56.50-105(a)(1).

3. **Section 2.5.4** In addition to the requirements of section 2.5.4, the wall thickness of pipes must be calculated using the ASME Code for Pressure Piping (ASME B31.1-2001). This requirement does not apply to the outer wall of required double wall piping systems.

4. **Section 2.5.16** The bunkering stations and associated gas piping may be located less than 760 mm from the ship's side as proposed. This allowance is based on the piping design providing sufficient flexibility to prevent collision damage to a bunkering station from propagating to the tank connection. You must provide sufficient information to demonstrate this to the Marine Safety Center and the OCMI.

5. **Section 2.8.1** In addition to the requirements of section 2.8.1, IGC Code independent tanks used to store liquefied natural gas must either:
   a. Meet 46 CFR 154.401 through 154.476 as applicable; or
   b. Meet ASME Boiler and Pressure Vessel Code (2010), Section VIII, Division 1 or 2 if the tank is a type C independent tank.

6. **Section 2.9.1.1** We understand from Glosten Associates' proposal that bunkering will be conducted after the last run of the day and before the first run of the next day when passengers or vehicles are not onboard. These operational controls satisfy Section 2.9.1.1 provided the vessel's Certificate of Inspection (COI) has an operational restriction that at a minimum states LNG bunkering operations are not allowed while vehicles or passengers are on the vehicle deck (note: bunkering operations are not considered complete until bunkering lines are inerted per Section 2.9.2). Please note: At this time the OCMI has indicated that vehicles and passengers will not be permitted on board the ferry during bunkering.

7. **Section 2.9.3.4** Ventilation for the gas fuel supply line ducting may be drawn from the engine room provided the engine room is fitted with gas detection as required in 3/D302 of the DNV Rules for Gas Fuelled Engine Installations (Jan, 2010) as proposed by Glosten Associates. The applicable safety functions listed in Section 6, Table B3, of DNV Rules for Gas Fuelled Engine Installations must be

followed, and the detection system must meet the additional conditions listed in comments for Section 5.5 below.

8. **Section 2.10.1** The following requirements are in addition to those in Section 2.10.1:
   a. A ventilation system must:
      (1) Not recycle vapor from ventilation discharges;
      (2) Have its operational controls outside the ventilated space, if the system is mechanical; and
      (3) Have a protective metal screen of not more than 13 mm (0.512 in.) square mesh on each ventilation intake and exhaust.
   b. Where artificial ventilation is applied to spaces which are not separated by gastight boundaries, underpressure must be maintained in the hazardous enclosed spaces in relation to the less hazardous spaces, and an over-pressure must be maintained in the non-hazardous enclosed spaces in relation to the adjacent hazardous spaces.

9. **Section 2.10.2.1** For any alternate installation to be considered, you must submit a safety analysis to the MSC demonstrating that the arrangement provides a level of safety equivalent to the requirements in Section 2.10.2.1.

10. **Section 2.10.2.2** The automatic fail-safe fire dampers must be type approved by this office.

11. **Section 3.2.4** Your proposed arrangement, which provides no physical boundary separating the bunkering stations from adjacent vehicle spaces, is accepted contingent on operational restrictions mandated by the OCMI as discussed in item 6 above.

12. **Section 3.3.2** Where water spray systems are used:
    a. Coverage for on-deck storage must include all exposed parts of the gas storage tank(s) located above deck and boundaries of the superstructures, compressor rooms, pump rooms, cargo control rooms, and any other normally occupied deck houses that face the storage tank.
    b. Each pipe, fitting, and valve must meet 46 CFR Part 56.
    c. Water spray nozzles are not required to be type approved by the Coast Guard.
    d. On vertical surfaces credit may be taken for rundown if the nozzles are spaced no more than 12 feet (3.7 m) apart vertically.
    e. The coverage of nozzles protecting valves, piping and manifolds must extend at least 19 inches (0.5 m) in each direction, past the protected fittings or to the area of the drip tray, whichever is greater.
    f. The main fire pumps may be used to supply the system if they are capable of providing the required flow for both systems. The water supply for the water spray system must be adequate to supply all nozzles simultaneously.
    g. Controls to remotely start pumps supplying the water spray system and operate any normally closed valves to the systems must be located in a readily accessible position which is not likely to be cut off in case of fire in the protected areas and be outside of the protected area.
    h. Each water spray system must have a means of drainage to prevent corrosion of the system and freezing of accumulated water in subfreezing temperatures.
    i. Final installation and arrangement of the water spray system shall be to the satisfaction of the OCMI.

13. **Section 3.3.3** Where dry chemical powder fire extinguishing systems are installed as required by IMO Resolution MSC.285(86) Section 3.3.3 the system must consist of at least one hand hose line unit that:

a. Is listed for fire service by a nationally recognized testing laboratory, as defined in 29 CFR 1910.7;
b. Meets the requirements of 46 CFR 154.1155 and 154.1165 – 154.1170; and
c. Meets the requirement of MSC.1/Circ.1315 (10 June 2009).

Note: There are no dry chemical powder fire extinguishing systems currently approved by the Coast Guard, therefore detailed manufacturer's data and a maintenance manual for the system to be installed must be provided to MSC for review as part of the detailed plan review package.

14. **Section 3.4.1** Instead of the requirements found in IMO Resolution MSC.285(86) Section 3.4.1, fire detection systems must:

a. Be provided in tank rooms.
b. Be provided in machinery spaces containing gas-fueled engines.
c. Be approved by the Commandant in accordance with 46 CFR 161.002 and installed in accordance with 46 CFR 76.27.
d. Have fire detection cables routed such that fire or flooding in one space will not affect the ability to detect fire in another space or fire zone; and
e. Provide heat detection in addition to any other forms of detection used for the protected space.

15. **Section 4.1** Hazardous locations must meet the following requirements in lieu of IMO Resolution MSC.285(86) Section 4.1. See comments under section 4.3 for classification of hazardous areas.

a. General requirements.
Electrical installations should not normally be in hazardous areas. Where necessary for operational purposes, the equipment must be located in the least hazardous area practicable.

b. Equipment and Installation Standards
Where electrical installations are in hazardous locations, they must comply with one of the standards listed in this paragraph, but not in combination in a manner that would compromise system integrity or safety:

(1) NEC 2011 (NFPA 70) Articles 500 through 504. Equipment identified for Class I locations must meet Sections 500.7 and 500.8 of the NFPA 70 and be tested and approved or certified by an independent laboratory accepted by the Coast Guard under 46 CFR Part 159, to the current version of any of the following standards:
(i) ANSI/UL 674, ANSI/UL 823, ANSI/UL 844, ANSI/UL 913, ANSI/UL 1203, ANSI/UL 2225, and/or UL 1604 (Division 2);
(ii) FM Class Number 3600, FM Class Number 3610, FM Class Number 3611, FM Class Number 3615, and/or FM Class Number 3620; or
(iii) CSA C22.2 Nos. 0-M91, 30-M1986, 157-92, and/or 213-M1987.
Note: See Article 501.5 of the NEC for use of Zone equipment in Division designated spaces.

(2) NEC 2011 (NFPA 70) Article 505. Equipment identified for Class I locations must meet Sections 505.7 and 505.9 of the NPFA 70 and be tested and approved or certified by an

independent laboratory accepted by the Coast Guard under 46 CFR Part 159, to the ANSI/ISA Series standards incorporated in NFPA 70 .
Note: See Article 505.9(c)(1) of the NEC for use of Division equipment in Zone designated spaces.

(3) IEC 60092-502 Electrical Installations in Ships, Tankers – Special Features (1999), except the following:
   (i) Paragraph d, Cable and wiring, of this section, applies in lieu of Clause 7.3.1.
   (ii) Ventilation alone may not be used as a means for reducing the classification of a hazardous space as indicated in Clauses 4.1.4, 8.3, and 8.4.
   (iii) The hazardous areas defined below under comments for Section 4.3 (Definition of hazardous area zones) apply in lieu of Clause 4.4.
   (iv) Electrical apparatus in hazardous locations must meet one or the combination of current versions of IEC 60079-1, -2, -5, -6, -7, -11, -13, -15, -18 and/or -27 in lieu of Clause 6.5.
   (v) Equipment must be certified by an IECEx System Ex Certification Body (ExCB) accepted by the Coast Guard under 46 CFR 159.010 in lieu of Clause 6.3. Certification under the European Union's (EU) ATEX Directive (94/9/EC) is not acceptable.

Note: IECEx System means an international certification system covering equipment that meets the requirements of the IEC 60079 series of standards. The IECEx system is comprised of an Ex Certification Body and an Ex Testing Laboratory that has been accepted into the IECEx System after satisfactory assessment of their competence to ISO/IEC Standard 17025, ISO/IEC Guide 65, IECEx rules of procedures, IECEx operational documents, and IECEx technical guidance documents as part of the IECEx assessment process.

In addition to paragraph b(1) of this section, electrical equipment that complies with NFPA 496 is acceptable for installation in Class I, Divisions 1 and 2. When this standard is used, it does not need to be identified and marked by an independent laboratory. The MSC will evaluate equipment complying with this standard during plan review. It is normally considered acceptable if a manufacturer's certification of compliance is indicated on a material list or plan.

For the standards in paragraphs b(2) and b(3) of this section, the encapsulating compound of ANSI/ISA 60079-18 and IEC 60079-18 (Ex "ma") certified equipment for installation in Class I Special Division 1 (Zone 0) hazardous locations must be compatible with LNG.

c. Lighting Systems

Lighting circuits serving flameproof or explosion proof lighting fixtures in an enclosed hazardous space or room must:

(1) Have at least two lighting branch circuits;
(2) Be arranged so that there is light for relamping any deenergized lighting circuit;
(3) Not have the switch and overcurrent device within the space for those spaces containing explosion proof or flameproof lighting fixtures.
(4) Have a switch and overcurrent protective device that must open all ungrounded conductors of the circuit simultaneously.

d. Cable and wiring

(1) Cable and wiring in hazardous areas must comply with the cable construction and testing requirements of current versions of IEEE Std 1580 (2001); UL 1309; MIL-C-24640B; MIL-C-24643A, or IEC 60092-350 (2008)/IEC 60092-353 Amendment 1, Annex A (2001), including the respective flammability tests contained therein, and must be of a copper-stranded type.
(2) For intrinsically safe systems, the wiring methods must meet Sections 504.20 and 504.30 of NEC 2011.
(3) Conduit and cable seals and sealing methods must meet Clause 6.8 of API 14F (1999).
(4) Type MC cables, when used, must meet the requirements in 46 CFR 111.60-23.

16. **Section 4.3** In lieu of IMO Resolution MSC.285(86) Section 4.3, hazardous areas are defined as noted below.

a. **4.3.1 Hazardous area zone 0**

The following are Class I Special Division 1 (Zone 0) locations:

(1) Interiors of LNG or CNG tanks, and any pipework of pressure-relief or other venting systems for the LNG or CNG tanks.
(2) A LNG or CNG pump room or compressor room*.
(3) Areas on an open deck, or semi-enclosed spaces on open deck, within 0.5 meters of any natural gas pump room or compressor room entrance, and pump room ventilation inlet or outlet.
(4) An enclosed or semi-enclosed space having an opening into a Class I Special Division 1 (Zone 0).

*The following are additional requirements related to hazardous locations for natural gas pump and compressor rooms:

(i) Providing ventilation to re-classify enclosed hazardous areas containing devices handling natural gas fuel is not allowed. These installations must comply with Clauses 6.3.1.2 of API 500 (2002) and 6.6.1.2 of ANSI API RP 505 (2002).
(ii) Where fitted, natural gas fuel pump and compressor rooms shall be isolated from all sources of vapor ignition by gastight bulkheads. The gastight bulkhead between the pump room and the pump-engine compartment may be pierced by fixed lights, drive shaft and pump-engine control rods, provided that cable bulkhead penetrations are provided with the appropriate cable sealing fittings, and the shafts and rods are fitted with fixed oil reservoir gland seals, or pressure grease seals where they pass through the gastight bulkheads. Other types of positive pressure seals must be specially approved by the Commandant (CG-521). Access to LNG or CNG pump enclosed area or room must be from the open deck.
(iii) Fixed lights in natural gas fuel pump and compressor rooms or enclosed areas must meet the arrangement and construction requirements in 46 CFR 111.105-31(g).
(iv) A natural gas fuel handling area or room that precludes the lighting arrangement of paragraph (iii) of this section, or where the lighting arrangement of paragraph (iii) of this section does not give the required light, must have explosion proof, flameproof (Ex "d") or flameproof-increased safety (Ex "de") lighting fixtures.
(v) Gas fuel pumps and compressors must shut-down automatically when the quick-closing shut-off valves are closed as required under IMO Resolution MSC.285(86) Section 5.6.

b. **4.3.2 Hazardous area zone 1**
The following are Class I Division 1 (Zone 1) locations:
(1) A tank room.
(2) A zone on the weather deck or a semi-enclosed space on the weather deck within 3.0 m (10 feet) of any LNG or CNG tank outlet, gas or vapor outlet, gas fuel pipe flange, valve, manifold, and machinery room ventilation hood or gas fuel piping ventilated pipe or duct outlet.
(3) Areas on an open deck, or semi-enclosed spaces on open deck, 1.0 meter beyond the areas in item (3) of the Class I Special Division 1 (Zone 0) locations listed above.
(4) Areas on the open deck within spillage coamings surrounding gas bunker manifold valves and 3 meters beyond these, up to a height of 2.4 meters above the deck.
(5) An enclosed space or semi-enclosed space having an opening into any Class I Division 1 (Zone 1).

c. **4.3.3 Hazardous area zone 2**
The following are Class I Division 2 (Zone 2) locations:
(1) Enclosed or semi-enclosed spaces, immediately above the tank room (for example between decks) or having bulkheads above and in line with gas-fuel tank room bulkheads.
(2) A zone on the weather deck or a semi-enclosed space on the weather deck within 1.5 m (5 ft) of the areas in items (2) through (4) of the Class I Division 1 (Zone 1) locations listed above.
(3) A zone within 2.4 m (8 ft) of the outer surface of a LNG or CNG tank where the surface is exposed to the weather.
(4) An enclosed space that shares a boundary with a tank room.

17. **Section 5.5** Gas detection systems must meet the following requirements in addition to IMO Resolution MSC.285(86) Section 5.5:

a. <u>Portable Gas Detectors</u>
Each vessel must have at least two portable gas detectors meeting the applicable equipment testing standards listed under paragraph f below.

b. <u>Gas detector certification</u>
All gas detection systems, including associated devices, and portable detectors must be certified by an independent laboratory accepted by the Coast Guard under 46 CFR Part 159, as meeting the requirements of 46 CFR 113.15-30 and certified for use in the appropriate hazardous area classification as described in 46 CFR 111.105. Where the fire and gas detection systems are combined, the system must also comply with 46 CFR 161.002.

c. Plan Submittal

In addition to the submission of typical new construction drawings, including such drawings reflecting the installation of an LNG fueled propulsion system, he following gas detection system plans must be submitted for review in accordance with 46 CFR 110.25-3:

(1) Arrangement and layout of system;
(2) Operational description of system;
(3) System block diagrams;
(4) User manual(s);
(5) Power supply arrangements;
(6) Equipment list;
(7) Circuit diagrams; and
(8) Independent laboratory certification and applicable test reports of the gas detection system.

d. Functional requirements for gas detection systems

(1) Gas detection systems must be designed such that when a detector actuates, the vessel operator is able to identify the specific gas detector and its location. The gas detection alarm system must have an indicator panel in each wheelhouse.
(2) Gas detection cables must be routed such that a fire or flooding in one space will not affect the ability to detect gas in another space or zone.
(3) Gas detection system shall be designed such that failure of one component or sub-system will not unduly affect any other system, sub-system or component and, as far as practicable, shall be detectable.
(4) Safety function shall be independent of control and monitoring (alarm) functions.
(5) Must provide two sources of power. Main power and emergency power are to be supplied to the gas detection system(s) from independent cabling systems.
(6) Power supplies and electric circuits necessary for the operation of the system shall be designed with self-monitoring properties for the loss of power.
(7) Simultaneous activation of gas detectors shall not impair the operation of the system.
(8) Provision of portable gas detection devices will be to the OCMI's satisfaction.

e. Required standards, testing and certification for gas detection systems and portable detectors

Portable gas detection equipment must be suitably marked for use in the hazardous (classified) location. The gas detection equipment should be listed by an independent laboratory accepted by the Coast Guard under 46 CFR Part 159, as meeting the following requirements:

f. Equipment Testing Standards

(1) Fixed oxygen analysis and gas detection equipment
  IEC 60945 (2002)
  IEC 60533 (1999)
  IEC 60079-29-1 (2007)
(2) Portable oxygen analysis and gas detection equipment
  IEC 60945 (2002)
  IEC 60533 (1999)
  IEC 60079-29-1 (2007)
  IEC 60079-0 (2004)
  IEC 60079-1 (2007)

IEC 60079-10 (2002)
IEC 60079-11 (2006)
IEC 60079-15 (2005)
IEC 60079-26 (2006)

18. **Section 5.6** Table 1, in Section 5.6 Safety functions of gas supply systems, is replaced with the table included as enclosure (1) to this letter.

This design basis is applicable to the Glosten Associates' May 16, 2011 proposal for the new 144-car ferry class of vessels. Any major departure will require reevaluation by this office.

As mentioned in your letter, we anticipate receipt of a similar conceptual design package for your existing Issaquah Class ferries. Although the gas-fueled system proposal for the Issaquah Class may be similar, it will require a separate review to ensure any issues unique to its design are adequately addressed.

For further clarification on any of these issues, please feel free to contact Mr. Tim Meyers of my staff at (202) 372-1365.

Sincerely,

J. D. REYNOLDS
Commander, U.S. Coast Guard
Acting Chief, Office of Design and Engineering Standards
By direction

Encl: (1) Safety Functions of Gas Supply Systems

Copy: USCG Marine Safety Center (MSC-2)
USCG Sector Puget Sound
USCG Liquefied Gas Carrier National Center of Expertise
Glosten Associates

144-Car Ferry LNG Fuel Conversion Feasibility Study

Life Cycle Cost Analysis

Prepared for
Washington State Ferries
Seattle, WA

File No. 11030.01
1 July 2011
Rev. -

THE GLOSTEN ASSOCIATES
Consulting Engineers Serving the Marine Community

144-Car Ferry LNG Fuel Conversion Feasibility Study

Life Cycle Cost Analysis

Prepared for
Washington State Ferries
Seattle, WA

File No. 11030.01
1 July 2011
Rev. -

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Section 4 Discussion **13**

Revision History

Section	Rev	Description	Date	Approved
All	-	Initial release	7/1/2011	DWL

References

1. Gas Fuelled Engine Installations," *Det Norske Veritas Rules for Classification of Ships,* Part 6 Chapter 13, 2011.
2. *Interim Guidelines on Safety for Natural Gas-Fuelled Engine Installations in Ships,* International Maritime Organization (IMO), Resolution MSC.285(86).
3. *Propulsion Study for a New 130 Car Ferry*, The Glosten Associates, Inc., 29 December 2003.
4. *New 130 Auto Ferry Increased Capacity Feasibility Study*, The Glosten Associates, Inc., 23 June 2005.
5. *New 144 – Auto Ferry, General Arrangements,* Washington State Ferries, Drawing No. 9000-660-001-01.
6. *New 144 – Auto Ferry, Machinery & Engineering Spaces Arrangement,* Washington State Ferries, Drawing No. 9000-660-050-01.
7. *New 144 – Auto Ferry, Electric One-Line Diagram*, Washington State Ferries, Drawing No. 9000-6674-090-01, Rev. A.
8. *WSF New 144 Car Auto Ferry Intact and Damaged Stability Calculations,* 9000-6674-001-16, 25 November 2008.
9. *144-Car Ferry LNG Fuel Conversion Feasibility Study Design Report*, The Glosten Associates, Inc., Rev -, 1 July 2011.
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11. *Piping Arrangement: Wärtsilä*, The Glosten Associates, Inc., Drawing 11030-500-03.
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13. *144-Car Ferry LNG Fuel Conversion Feasibility Study Life Cycle Calculation Workbook*, The Glosten Associates, Inc., Rev -, 1 July 2011.
14. *Rolls Royce proposal*, scope of supply, and technical specification
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16. *Regulatory Submittal Package*, The Glosten Associates, Inc., Sent to USCG and DNV on 18 May, 2011

Executive Summary

Washington State Ferries (WSF) is investigating powering the new 144-Car Ferries with liquefied natural gas (LNG) fuel which has potential to reduce operational costs and air emissions when compared to diesel fuel. However, converting to LNG poses technical, regulatory, and economic challenges compared to diesel. The Glosten Associates (Glosten) was tasked to study both the technical and economic feasibility of such a conversion and to identify risks. This study finds that the conversion is both technically feasible and cost effective though technical and regulatory challenges remain. The basis for the cost analysis is the design described in the *144-Car Ferry LNG Fuel Conversion Feasibility Study Design Report* (Ref. 9) as well as cost information provided by WSF and equipment vendors.

There is a higher capital investment required for changing the design to LNG, when compared to diesel. However, the LNG option brings an operational costs savings of approximately $1M per year per vessel. As a result of the fuel cost savings the payback period of the additional capital cost is approximately 6 years.

Three propulsion system design options were evaluated and compared:

1. The existing diesel fueled design with equipment provided by EMD;
2. A dual fuel (LNG/Diesel) design with equipment provided by Wärtsilä;
3. A single fuel (LNG) design with equipment provided by Rolls Royce.

The capital, operational, and lifecycle costs were calculated for all three options. Because the study was for alternative options for main engines and fuel systems, only the costs directly associated with the three propulsion system options were included in the costs. All costs of common elements of the vessel design not related to or impacted by the propulsion system design were excluded. These excluded baseline costs should be considered by WSF in the total vessel capital, operational, and lifecycle costs but are not relevant for a comparison of propulsion system options.

The lifecycle costs, which include both capital and operational costs, were calculated over 30 years. The capital cost estimate includes the installed cost of main engines and gas system equipment as well as additional commissioning, testing, and regulatory approvals needed to accommodate the use of LNG fuel. The operational cost estimate includes the maintenance and repair of the engines and gas systems as well as the consumption of diesel oil, LNG, and lube oil. An inflation rate of 3% per year was used for the operational costs.

The calculated costs of the three options are presented in the following table.

Design Option	**Capital Cost**	**30 Year Lifecycle Costs**			**Annual Operational Cost (First Year)**
		Nominal Cost	**Present Value Cost (3% Discount Rate)**	**Present Value Cost (5% Discount Rate)**	
EMD (Diesel Fuel)	$2.45M	$130.00M	$ 80.54M	$ 61.22M	$ 2.68M
Rolls Royce (Gas Fuel)	$9.93M	$76.95M	$50.96M	$40.81M	$ 1.41M
Wärtsilä (Dual Fuel)	$8.52M	$ 93.05M	$ 60.27M	$ 47.47M	$ 1.78M

Section 1 Introduction

Washington State Ferries (WSF) is investigating powering the new 144-Car Ferries with liquefied natural gas (LNG) fuel. The new 144-Car Ferry class is a completed diesel powered vessel design that has not been built to date. Since the design has been carried to a production ready level, a conversion of the existing design is more desirable than a new and optimized design. The design conversion would allow new vessels to be built to utilize LNG as fuel, while maintaining the integrity of the current design.

Glosten was commissioned to study the feasibility of converting the existing diesel fuelled vessel design to LNG fuel. As part of the study, Glosten was tasked with conducting a life cycle cost analysis comparing the capital and lifecycle costs of the existing diesel fueled design and a LNG fuelled design.

An LNG design concept has been developed to retain as much of the existing design as possible while meeting the operational requirements of the ferry service as well as complying with regulatory requirements. The basis for the cost estimate is the design described in the Design Report (Reference 9) as well as cost information provided by WSF and equipment vendors. Three options were evaluated:

- The existing diesel fueled design (equipment provided by EMD)
- A dual fuel design, LNG/Diesel (equipment provided by Wärtsilä)
- A single fuel design, LNG only (equipment provided by Rolls Royce)

Section 2 Methodology

2.1 Capital Costs

Capital costs for main engines and gas storage and supply systems were determined as follows:

- Vendor supplied equipment costs were provided by Rolls Royce and Wärtsilä.
- Capital costs for the existing diesel engines were provided by WSF.
- Shipyard installation costs were estimated based on the design outlined in the Design Report (Reference 9).
- Slight differences in the scope of vendor provided equipment are discussed in this report and have been compensated for in the shipyard installation costs.
- Regulatory comments with a cost impact have been incorporated, where appropriate.

All capital costs were estimated in today's dollars (2011). Inflationary adjustments would be required if capital equipment and shipyard contracts are procured at a later date. As the existing detail design of the diesel powered vessel is nearing completion, additional engineering costs would be required to incorporate the required design modifications for operation on LNG. These engineering costs were not included in the capital costs, but are considered in this report.

2.1.1 Rolls Royce Scope of Supply

The Rolls Royce proposal included the following main components:

- 2 - Main engine (Bergen C26:33L9PG developing 2,190 kW (2,937 HP) at 900 RPM) with auxiliary equipment and exhaust silencer
- 1 - LNG bunkering system (no piping)
- 2 - Gas storage tanks (95 m^3 (25,096 gallon) tank skids)
- 2 - Gas vaporization and heating systems
- Gas supply equipment (no piping)
- Controls for the engine and gas systems
- Gas detection system
- No delivery
- Technical documentation
- 85 man-days of commissioning.

The proposed scope of supply and cost are included in Reference 14.

2.1.2 Wärtsilä Scope of Supply

The Wärtsilä proposal included the following main components:

- Main engines (Wärtsilä 6L34DF developing 2,300 kW (3,084 HP) at 750 RPM)
- 1 - LNG bunkering system and 65m (213 ft) piping
- Gas storage system (LNGPac 194) comprised of a single 194 m^3 (51,249 gallon) tank
- Gas vaporization and heating systems including glycol-water heating system

- Gas supply equipment (no piping)
- Controls for the engine and gas systems
- No gas detection system
- Delivery to Seattle, WA
- Technical documentation
- 60 man-days of commissioning and 3 man-days of sea trial participation

The proposed scope of supply and cost are included in Reference 15.

2.1.3 Shipyard Installation

It is assumed that installation of equipment that is not part of the existing diesel fuelled vessel design will increase the shipyard installation costs. These costs have been estimated. No installation cost changes are assumed where equipment in the existing diesel vessel design has been replaced with similar equipment in the gas fuelled vessel designs. For example, the existing design requires engine foundations and a similar but different foundation would be required for the gas design.

Shipyard supplied equipment and labor have been estimated with a burdened labor rate of $65/hr. Shipyard markups on capital costs have not been estimated. It is assumed that major capital equipment will be owner furnished. The shipyard installation costs are slightly different between the two gas vendors due to minor differences in scope of supply and gas system arrangement.

2.1.4 Design Engineering

As the existing diesel powered vessel design is nearly production ready, additional costs would be incurred to modify the design for operation on LNG fuel. These costs would be a onetime expense and are not significantly affected by the choice of gas supply and engine vendor.

The contract design effort for a gas fuelled vessel will involve selecting a vendor(s) for major equipment and developing the design to a level that can support an accurate shipyard bid. This effort assumes the following:

- Revision of arrangement drawings to include the selected major equipment vendor(s).
- System calculations and engineering necessary to determine secondary equipment requirements.
- System schematics and electrical diagrams for all systems revised as necessary to support the LNG design.
- Secondary support equipment is sized but specific vendors are not selected.
- Regulatory submittal of contract design for initial review prior to release for bid.

The preliminary design described in Reference 9 has been designed to meet the requirements of References 1 and 2, as well as the relevant USCG rules. The designed has been reviewed by both the USCG and Det Norske Veritas (DNV), the Norwegian classification agency with over 10 years of experience in classification of LNG fuelled ships. Written comments that clarify design requirements, and provide additional guidance that will be needed in the development of the contract and production designs have been received from both agencies (References 17 and 18).

While regulatory design review of a preliminary package is atypical, it was considered necessary and was encouraged by the regulators since the technology is just emerging in this country. WSF believes that early involvement of USCG will minimize schedule and cost risk. However, even with early involvement from regulators, an additional cost to WSF for regulatory approvals has been assumed to be approximately $350,000. Developing a contract and production design packages is assumed to add approximately $550,000.

2.1.5 Existing Equipment

WSF has already procured some of the major equipment for the propulsion system including the main diesel engines, reduction gears, propellers, and shafting for the first four vessels in the class. The capital costs for the previously procured equipment is not included in the capital cost changes for the new vessels. However, sunk costs associated with this equipment have been quantified for the first four vessels.

It is noted that six of the eight main diesel engines that were previously purchased have subsequently been used in the construction of the new 64-Car Ferries. The two remaining engines are of the same rotation direction which means that only one of the existing engines could be used in each of the first two new 144-Car Ferries, should they be fuelled by diesel. Four ship sets of the other propulsion equipment procured are still available for construction of the new vessels.

In order to compare capital costs equally, the cost of the main engines was included in the capital cost of the baseline (diesel) design. The engine cost was included as new engines would need to be purchased for all of the new vessels. However, as previously noted, one existing engine is available for each of the first two vessels. The cost of the existing engines was estimated by WSF to be $2,400,000 per ship set ($1,200,000 per engine). If the first two vessels were to be built with gas engines, an additional $1,200,000 cost for each of the two vessels would be incurred due to the sunk cost of the existing engines.

If the Wärtsilä engines are used, the existing reduction gears could not be used. This is because the Wärtsilä engines operate at 750 RPM and the existing reduction gears were designed for a 900 RPM input. The cost for the existing gears was estimated by WSF as $1,300,000 per ship set ($650,000 per reduction gear). If the first four vessels were to be built with Wärtsilä engines, an additional $1,300,000 cost for each of the four vessels would be incurred due to the sunk cost of the existing reduction gears.

2.1.6 Other Design Changes

The existing diesel fuelled vessel design, which is powered by EMD engines, was used as a baseline for the lifecycle cost. Only modifications required to accommodate the gas propulsion system were considered. It may be possible to realize some cost savings from additional optional design modification for a gas fuelled vessel. For example when switching to a gas system the required diesel storage capacity is drastically reduced. Removal or reduction of the existing double bottom diesel fuel tanks could provide cost savings. A review of the existing design with cost savings in mind is recommended to determine potential cost reductions in the gas fuelled vessel design.

2.2 Operational Costs

2.2.1 Route and Operating Profile

To simplify the calculation of operating costs, a representative average operating route was chosen, rather than a specific vessel route. The operating profile for the route is the same as was used for the 2003 WSF propulsion study, Reference 4. The engine power for transit, however, was updated to reflect the cruising power for the 144-Car Ferry. Table 1 shows the operating profile assumed in the analysis.

Table 1 Power Requirements and Annual Operating Profile Hours

Condition	Engine Power (kW)	No Engines	Total Power (kW)	Hours	Operating (kWh/year)
Transit	1,721	2	3,441	3,000	10,323,000
Maneuvering	391	2	781	1,000	781,000
Docked	379	1	379	2,000	758,000
Total				6,000	11,862,000

2.2.2 Fuel and Lube Oil Costs

The consumption of diesel fuel, gas fuel, and lube oil was calculated. The annual fuel consumption was calculated using the specific fuel consumption curves developed in Reference 9 and the annual operating hours at the various power levels. The lube oil consumption was calculated using the specific lube oil consumption given in the engine technical performance guides. The diesel fuel consumption for auxiliary generators is assumed to be the same for all three designs and therefore was not considered when comparing operating costs.

Table 2 Consumables

Operating Condition	Specific Fuel Gas (kJ/kWh)	Total Fuel Gas (gal/yr)	Specific Fuel Oil (g/kWh)	Total Fuel Oil (gal/yr)	Specific Lube Oil (g/kWh)	Total Lube Oil (gal/yr)
Rolls Royce						
Transit	7,619	1,022,334	0	0	0.4	1,246
Maneuvering	8,667	88,037	0	0	0.4	94
Docked	8,683	85,500	0	0	0.4	91
Wärtsilä						
Transit	8,253	1,107,424	2.92	8,958	0.4	1,246
Maneuvering	11,473	116,530	10.59	2,457	0.4	94
Docked	11,517	113,399	10.70	2,407	0.4	91
EMD						
Transit	0	0	194.84	597,070	0.206 gal/hr	1,236
Maneuvering	0	0	215.10	49,895	0.206 gal/hr	412
Docked	0	0	215.25	48,404	0.206 gal/hr	412

The prices used for fuel were based on recent fuel price prices received from WSF. The price of marine diesel oil (MDO) was assumed to be $3.65 per gallon. The price of LNG was assumed to be $1.05 per gallon. The MDO was assumed to have a density of 3.37 kg/gal and lube oil was assumed to have a density of 3.31 kg/gal. The LNG was assumed to have an energy content of 76.94 mJ/gal. A 3% annual inflation rate was assumed for all consumables. No fuel oil price escalation rate was assumed.

2.2.3 Maintenance and Repair Costs

The maintenance and repair (M&R) costs were calculated for both the main engines and the gas system. Estimated M&R parts costs for the main engines were provided by all three engine vendors. Estimated M&R labor hours were provided for the EMD engines and the Rolls Royce engines. The M&R labor hours were not provided for the Wärtsilä engines and were therefore estimated to be the average annual M&R labor hours from the other two engines. A 3% annual inflation rate was assumed for all maintenance and repair costs.

The M&R costs were also estimated for the gas systems. An annual, 6,000 hour, maintenance interval was assumed for routine maintenance of valves, operators, heat exchangers, and pumps. It was also assumed that all the tanks, gasification equipment, and gas supply units will undergo an overhaul every 30,000 hours (5 years). No vendor maintenance information was supplied and labor and materials costs were estimated for all gas system M&R events.

2.3 Present Value of Cost

All lifecycle and capital costs were calculated in nominal dollars and then discounted to a present value. Because no discount rate was specified by WSF, the present values were calculated for discount rates of both 3% and 5%. These discount rates were assumed to bracket the cost of capital if the project were to be funded with state issued bonds.

The cost of capital was assumed to be the same as the discount rate such that the cost of capital and the discount rate cancel each other out for initial capital expenditures. Therefore the nominal capital cost and the present value capital cost are the same.

Section 3 Results

The costs presented in this report are considered Rough Order of Magnitude (ROM) estimates intended to capture the magnitude of the overall costs. The accuracy of a ROM cost is expected to be +/- 30% because the design that forms the basis for the enclosed estimates is preliminary. Typically, project costs are refined as a design is developed to a higher level of detail. These costs are intended to assist WSF in the decision to invest in the LNG propulsion system and give an estimate for expected capital outlays and payback time.

Vessel operating costs are estimated based on fuel costs available at the time the report was written. Significant changes in the 30 year projected costs can be seen with slight variations in fuel costs. For this report it is assumed that both diesel and gas fuel increase at a 3% inflation rate over the 30 year projection. Actual fuel costs are often volatile and unpredictable. If gas prices increase at a faster rate than diesel prices the projected cost differences will be reduced. If diesel prices increase faster than gas prices the projected cost differences will be increased.

3.1 Capital Cost

3.1.1 Equipment Costs

Table 3 summarizes the additional capital costs per vessel for the main engines and gas storage and supply systems for each of the three options. Details of the vendors' scope of supply are included in References 13, 14, and 15. Details of the shipyard costs are included in Reference 13. Not included in these totals are the additional sunk costs incurred for the first four vessels that have pre-purchased equipment and the non-recurring design costs for converting the design to LNG fuel. Both of these costs are addressed separately.

Table 3 Capital Cost Summary (Per Vessel)

Description	Wärtsilä	Rolls Royce	EMD
Total Capital Cost	$ 8,520,971	$ 9,930,108	$ 2,452,000

3.1.2 Design Costs

There are design costs associated with the modification of the existing diesel fuelled vessel for operation on LNG. However, these costs will only be incurred in the development of the first vessel and will not recur with subsequent vessel in the class. Because these costs are non-recurring, they were not included in the capital cost of the vessel, but should still be considered in the overall cost of the 144-Car Ferry program. The non-recurring design costs are summarized in Table 4.

The EMD design is the current diesel powered design and would not require additional design work. The Wärtsilä contract and production design costs are slightly higher as new reduction gears would be required and gear foundation modifications are likely required. The Rolls Royce design would require an additional enclosure to be designed around the gas supply unit.

Table 4 Non-recurring Design Cost Summary

Description	Wärtsilä	Rolls Royce	EMD
Contract Design	$ 260,000	$ 250,000	$ -
Regulatory Liaison & Submittal	$ 100,000	$ 100,000	$ -
Design Classification Review	$ 250,000	$ 250,000	$ -
Production Design	$ 320,000	$ 310,000	$ -
Total Design Costs	$ 830,000	$ 810,000	$ -

Operational Cost

Table 5 summarizes the first year per vessel operational costs for each of the three options. Details of the operational costs are included in Reference 13.

Table 5 First Year Operational Cost Summary (Per Vessel)

Description	Wärtsilä	Rolls Royce	EMD
Main Engine & Gas System			
Fuel Oil Cost	$ 50,451	$ -	$ 2,538,101
Fuel Gas Cost	$ 1,404,220	$ 1,255,664	$ -
Lube Oil Cost	$ 7,157	$ 7,157	$ 10,300
M&R Cost	$ 301,408	$ 124,843	$ 132,620
Gas Storage and Vaporization			
M&R Cost	$ 13,580	$ 21,060	$ -
Projected Cost (Nominal $)	$1,776,816	$ 1,408,725	$ 2,681,021
Present Value Cost (3% Discount Rate)	$1,725,064	$ 1,367,694	$ 2,602,933
Present Value Cost (5% Discount Rate)	$1,692,205	$ 1,341,642	$ 2,553,354

Table 6 summarizes the total per vessel operational costs over 30 year for each of the three options. Details of the operational costs are included in Reference 13.

Table 6 30 Year Operational Cost Summary (Per Vessel)

Description	Wärtsilä	Rolls Royce	EMD
Main Engine & Gas System			
Fuel Oil Cost	$ 2,400,216	$ -	$ 120,751,219
Fuel Gas Cost	$ 66,806,331	$59,738,750	$ -
Lube Oil Cost	$ 340,514	$ 340,514	$ 490,027
M&R Cost	$ 14,339,611	$ 5,939,453	$6,309,452
Gas Storage and Vaporization			
M&R Cost	$ 646,074	$ 1,001,938	$ -
Projected Cost (Nominal $)	$ 84,532,746	$ 67,020,656	$130,002,698
Present Value Cost (3% Discount Rate)	$ 51,751,914	$ 41,030,812	$80,539,996
Present Value Cost (5% Discount Rate)	$ 38,946,575	$ 30,878,270	$61,218,135

3.2 30 Year Lifecycle Cost

Table 7 summarizes the total 30 year per vessel lifecycle cost with and without a discount rate. The total lifecycle costs are the sum of the capital costs (Table 3) and 30 year operational costs (Table 6). Not included in lifecycle costs are the additional sunk costs incurred for the first four vessels that have pre-purchased equipment (Table 9) nor additional non-recurring design costs (Table 4).

Table 7 Total 30 Lifecycle Cost Summary (Per Vessel)

Description	Wärtsilä	Rolls Royce	EMD
Projected Cost (Nominal $)	$ 93,053,716	$ 76,950,764	$ 130,002,698
Present Value Cost (3% Discount Rate)	$ 60,272,884	$ 50,960,920	$ 80,539,996
Present Value Cost (5% Discount Rate)	$ 47,467,545	$ 40,808,378	$ 61,218,135

3.3 Existing Equipment

The first four planned vessels in the 144-Car Ferry class have some equipment pre-purchased. The pre-purchased equipment is listed in Table 8. The majority of this equipment has been incorporated into the gas powered design. The exceptions are the two EMD diesel engines (one for each of the first two vessels) and the reduction gears, if a Wärtsilä design is chosen.

Table 8 Pre-Purchased Equipment

Vessel	Engines (1)	Gears	CPP Propellers	Propeller Shafting	Combining Shafting
1	1	2	2	2	1
2	1	2	2	2	1
3	0	2	2	2	1
4	0	2	2	2	1
5 +	0	0	0	0	0

(1) Two opposite handed engines required

The pre-purchased equipment that would not be able to be used is a sunk cost that must be added to the capital cost of vessels one through four. Table 9 summarizes the sunk cost per vessel for the first four vessels in the 144-Car Ferry class. Any salvage value of the existing equipment has not been included.

Table 9 Sunk Cost per Vessel for Initial Vessels in Class

Vessels	Wärtsilä	Rolls Royce	EMD
1 & 2			
Engines	$1,200,000	$1,200,000	$ -
Gears	$1,300,000	$ -	$ -
Total	$2,500,000	$1,200,000	$ -
3&4			
Engines	$ -	$ -	$ -
Gears	$1,300,000	$ -	$ -
Total	$1,300,000	$ -	$ -
5+	$ -	$ -	$ -

For vessels built after the first four vessels in the 144-Car Ferry class, there are no sunk costs and the capital costs shown in Table 3 and the 30 year lifecycle costs shown in Table 7 are applicable.

Section 4 Discussion

Modifying the existing design for gas operation will result in substantial operational costs savings. Based on the analysis conducted for this study, both gas fuelled vessel designs have the potential of achieve an annual reduction in operating costs of over $1 million per vessel when compared to the baseline diesel fuelled vessel design. The modification of the vessel design for LNG fuel will result in a higher capital cost of the vessel. However, the operational cost savings offset the increased capital cost, and a payback period of approximately 6 years is anticipated for the gas fuelled vessel designs. It should be noted that the payback period will be longer for the first vessels in the class due to sunk costs.

While difference in 30 year lifecycle cost between the diesel fuelled vessel design and the gas fuelled vessel designs is clear, the differences in lifecycle costs between the two gas fueled design are smaller. Over the 30 year lifecycle the Rolls Royce design has lower costs.

Capital costs in this report only consider modifications to the propulsion system. Costs for the construction of the balance of the vessel are not considered in this report. Existing cost estimates and bids must be combined with these costs to develop overall vessel costs.

The capital costs vary widely between the three vessel designs. The existing EMD design has the least capital costs as the design matches the existing design. The Wärtsilä platform has a lower upfront cost than the Rolls Royce option. The difference in capital costs between Wärtsilä and Rolls Royce is reduced for the first four vessels because additional sunk costs are incurred for the Wärtsilä option. However, taking the added sunk costs into account, the capital outlay for a Wärtsilä system is still slightly lower than Rolls Royce.

The operational cost for the Wärtsilä system is higher than for the Rolls Royce design due to the higher specific fuel consumption of the Wärtsilä engines. Therefore, over the 30 year period the Rolls Royce system has the lowest lifecycle cost.

Evaluating the Use of Liquefied Natural Gas in Washington State Ferries

Final Report

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The cover photo shows the Norwegian ferry operator Fjord1's newest LNG fueled ferry.

EXECUTIVE SUMMARY

The 2011 Legislature directed the Joint Transportation Committee to investigate the use of liquefied natural gas (LNG) on existing Washington State Ferry (WSF) vessels as well as the new 144-car class vessels and report to the Legislature by December 31, 2011 (ESHB 1175 204 (5)); (Chapter 367, 2011 Laws, PV).

Liquefied natural gas (LNG) provides an opportunity to significantly reduce WSF fuel costs and can also have a positive environmental effect by eliminating sulfur oxide and particulate matter emissions and reducing carbon dioxide and nitrous oxide emissions from WSF vessels.

This report recommends that the Legislature consider transitioning from diesel fuel to liquefied natural gas for WSF vessels, making LNG vessel project funding decisions in the context of an overall LNG strategic operation, business, and vessel deployment and acquisition analysis. The report addresses the following questions:

- *Security.* What, if any, impact will the conversion to LNG fueled vessels have on the WSF Alternative Security Plan?
- *Vessel acquisition and deployment plan.* What are the implications of LNG for the vessel acquisition and deployment plan?
- *Vessel design and construction.* What design and construction constraints should be considered in making LNG decisions?
- *Vessel operation.* How will LNG fueled vessels affect bunkering and other WSF operations?
- *Business case.* What is the most cost-effective scenario to introduce LNG fueled vessels to the WSF fleet considering both operation cost savings and capital project costs?

LNG AS A MARINE FUEL SOURCE

Liquefied natural gas (LNG) is natural gas that has been cooled to -259 degrees Fahrenheit at which point it is condensed into a liquid, which is colorless, odorless, non-corrosive, and non-toxic. LNG is a cryogenic liquid meaning that it must be kept cooled to -259^{o} F or it returns to its gaseous state.

LNG takes up about 1/600th of the volume of natural gas in the gaseous state. This makes it cost efficient to transport in specially designed cryogenic LNG carriers over long distances opening up market access to areas where pipelines do not exist and/or are not practical to construct.

There are currently few LNG marine applications in use in the world. LNG carriers, that carry LNG as cargo and use the boil-off from the storage tanks and oil as fuel sources, have been in service since 1959 and there are more than 300 in use around the world. The first LNG passenger vessel did not begin service until 2000 in Norway, the only country currently operating LNG passenger vessels. There are LNG passenger vessels under construction or in design for service in Argentina-Uruguay, Quebec, and Finland-Sweden. Norway also operates a small number of LNG offshore supply and coast guard vessels.

LNG Fueled Ferries - Norway

Norway is the world leader in LNG fueled passenger vessels and today operates the only LNG fueled ferries in the world.

The first Norwegian LNG ferry, Fjord1's *Glutra,* was built in 2000 with government assistance. In 2011, Fjord1 has 12 LNG ferries operating in Norwegian waters and more under construction. Other Norwegian ferry operators also have LNG ferries including: Tide Sjo which has three; and Fosen Namos

Sjo which has one. Norway provides various tax incentives, primarily through carbon tax credits, and access to special funding that supports the construction and operation of LNG ferries.

The consultants met with representatives of Fjord1, Tide Sjo, and Gasnor, a Norwegian LNG supplier, in Norway finding:

- *Capital cost.* The cost of building the LNG ferries is 15-20 percent higher than diesel ferries. Norwegian ferry operators are eligible for a subsidy of up to 80 percent of the cost for projects that reduce NOx emissions from the NOx Foundation.
- *Carbon tax credits*. Norwegian ferry operators are able to avoid carbon taxes on natural gas that is used in lieu of diesel, which lowers the operations cost for LNG fueled vessels.
- *Maintenance and operation cost*. Fjord1 and Tide Sjo state that while maintenance costs were initially higher on the first LNG vessels they are now comparable between the two types of vessels.
- *Crew size and training.* Crew size is the same as on the diesel-powered ferries. Crew training for Fjord1 includes a gas course including risk aspects, emergency shutdown (ESD) philosophy, gas plant and demonstration of gas explosions. All Tide Sjo crew members on the LNG powered ferries must take a two-day gas training course then go through familiarization on the vessel before taking part in the bunkering process.
- *Cost of LNG.* The cost of natural gas in Norway has been close to, or slightly above, diesel and the energy cost of the LNG ferries has been slightly higher than diesel ferries. The cost of natural gas and diesel rise and fall together in Norway, which has not been the case in the United States.
- *LNG Supply.* The LNG used by the three Tide Sjo vessels is delivered from Bergen, a 322 mile drive, the longest distance Gasnor delivers LNG with their fleet of 16 supply trucks. They also have supply vessels that deliver LNG to coastal facilities.
    - *Testing.* It is important to test the vessel engines with the LNG that will be used as the gas composition varies by source. These three vessels were built in France and they brought LNG from Norway to test the engines.
    - *Shoreside fixed fueling facilities and tanks*. Shoreside fixed fueling facilities can save money and ease concerns about on-time delivery, but it only makes sense if there is enough LNG consumption to justify the capital expense.
    - *Contracts*. Gasnor generally enters into long-term 7-10 year contracts that have a fixed side that adjusts with the consumer price index and a commodity side that adjusts with the fluctuations in gas price.
- *Security planning and community outreach.* Security planning is much less elaborate than will be required in the United States. Tide Sjo officials indicated no significant public outreach effort regarding safety was needed. Gasnor, their LNG supplier, led the safety planning, which consisted of a four-hour planning meeting with local fire and police officials to develop an emergency response plan.
- *Vessel design.* All of Tide Sjo and Fjord1s LNG fueled ferries are built to emergency shutdown (ESD) standards for the engine room and have the LNG storage tanks below deck.

LNG Fueled Ferries – North America

BC Ferries and Staten Island Ferries are analyzing retrofitting vessels from diesel to LNG fuel. The Société des traversiers du Québec (STQ) – the Quebec Ferries Company – has contracted for three new LNG ferries.

CNG

Compressed natural gas (CNG) has not been found to be a viable marine fuel for vessels of WSF size and fueling requirements because it is not volume efficient. However, recent local developments may make it a possibility for WSF. While CNG has advantages (it is a non-cryogenic product and does not have the potential to create a vapor cloud) it would require daily fueling, which may not be feasible.

SECURITY AND OPERATION PLANNING

Security and operation planning and the associated public outreach are critical to WSF's ability to operate LNG fueled vessel.

The security planning process anticipated by WSF is a modified version of the process the United States Coast Guard (USCG) uses for the review of waterfront liquefied natural gas facilities. The process is outlined in the USCG's Navigation and Vessel Inspection Circular (NVIC) No. 01-2011 Guidance Related to Waterfront Liquefied Natural Gas Facilities and would be coordinated by the USCG. The process will allow inter-agency coordination between federal, state, and local public safety officials, encompass the entire WSF service area, and can include stakeholders such as members of the public and/or representatives of the Ferry Advisory Committees.

WSF will support the security planning process with public outreach. There is no U.S. experience with the introduction of a LNG passenger vessel or ferry to U.S. waters. LNG terminals have been very controversial, but are different from the introduction of a LNG fueled ferry.

The security planning process and associated public outreach are anticipated to take 18 months at a cost of $1.0 million.

Until the security planning review is complete it will also be difficult to know what, if any, additional operation cost may be incurred by WSF or the Washington State Patrol. A full cost-benefit analysis cannot be developed until this information is available.

WSF VESSEL ACQUISITION AND DEPLOYMENT PLAN

WSF has 22 vessels that serve its ten routes in Puget Sound and the San Juan Islands. WSF's Long-Range Plan assumes a 22 vessel fleet through 2030 and establishes a route service plan based on a vessel acquisition and retirement plan.

Funding has been provided in the 2011-13 biennium for the construction of a new 144-car vessel with a diesel engine. WSF has awarded the contract for this vessel with delivery in February 2014. The 16-year plan (2011- 2027) anticipates a second new 144-car vessel which may be LNG or diesel.

According to the WSF Long-Range Plan, the first new 144-car vessel will allow the *Evergreen State* to retire. The second new 144-car vessel allows the *Hiyu* to retire and for service expansions. The WSF Long-Range Plan calls for five additional new 144-car vessels to be built between 2025-2031, which will allow for the retirement of the two remaining Evergreen State class vessels and three Super class vessels.

The first Issaquah class retrofit vessel will have a total project time of 28 months, including 8 months out-of-service time for construction, staff training and sea trials. The second new 144-car vessel will take an extra year if funding is provided for the vessel and it is built as a LNG rather than a diesel fueled vessel.

Impact of LNG Retrofits or New Construction on Vessel Acquisition & Deployment Plan

Retrofitting the Issaquah class vessels will have a greater impact on the fleet acquisition and deployment plan than constructing a new 144-car vessel as an LNG vessel. The retrofits cannot begin until the fall of 2014 following the return of the Super class *Hyak* to service from its major renovation. If the Issaquah class retrofits begin before the second new 144-car vessel is in the fleet, WSF plans to retain the *Evergreen State* in service to provide coverage. If not for the retrofit of the Issaquah class vessels, the Evergreen State would retire when the first new 144-car diesel fueled ferry comes on line in 2014.

Once a second new 144-car vessel is in the fleet, WSF can both retrofit the Issaquah class vessels and retire the *Evergreen State.* To avoid disrupting service during the peak summer months, WSF plans to retrofit one Issaquah class vessel per year taking the vessel out-of-service during the fall through early spring. It will therefore take at least six years to complete the full retrofit of the Issaquah class vessels.

Delaying the delivery of the second new 144-car vessel by one year to accommodate its conversion to LNG will delay the planned service improvements and retirement of the *Hiyu* and will require the *Evergreen State* to stay in service if WSF proceeds with the retrofit of the Issaquah class vessels.

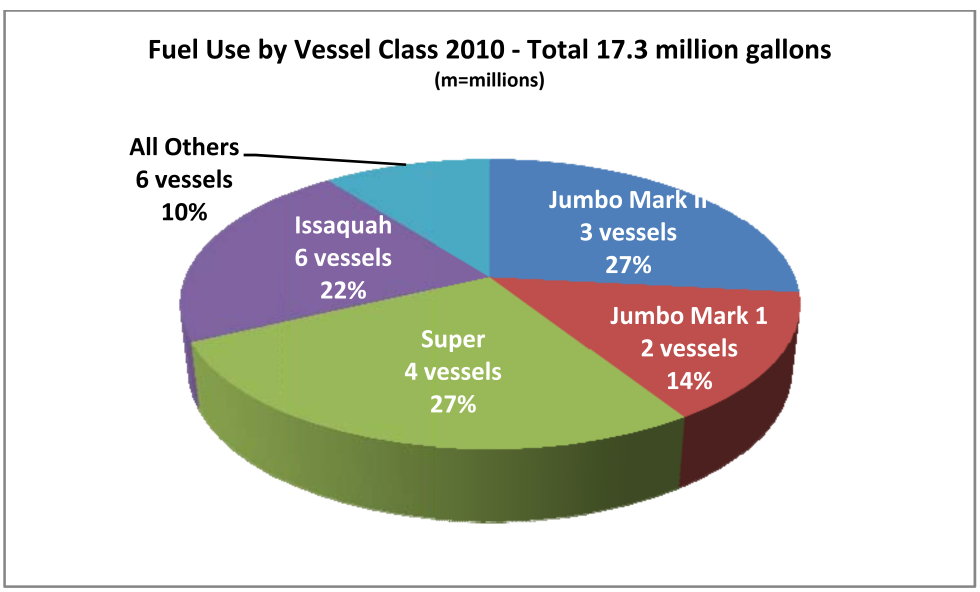
Designing a new 144-car vessel as a LNG fueled vessel could be considered in the context of the next planned procurement of five new 144-car vessels. If funding were available, a new 144-car LNG vessel could be viewed as the first of six such vessels.

WSF DIESEL FUEL AND LNG FUEL

Diesel Fuel Use

WSF fuels its fleet with a blend of biodiesel and ultra low sulfur diesel (ULSD). Fuel consumption is affected by the size of the vessel, the route the vessel is assigned to, and the speed of the vessel.

In 2010 WSF used 17.3 million gallons of fuel. The breakdown by vessel class is shown in the chart below.



In 2010 WSF had 21 vessels. As of 2011 the fleet has 22 vessels.

Diesel Fuel Cost

Diesel fuel represents 29.2 percent of the 2011-13 biennium operation budget for WSF or $135.2 million. Using the September 2011 forecast by the Transportation Revenue Forecast Council diesel fuel costs of $3.77 per gallon with taxes and allowance for biodiesel are projected for FY 2012. The cost per gallon will drop to $3.59 in FY 2014 as a result of legislative action to eliminate WSF's fuel sales tax effective July 2013. The price of ULSD is expected to increase from $3.59 per gallon in FY 2014 to $4.03 per gallon by the end of the 16-year financial plan in FY 2027.

Diesel fuel costs have been very volatile, peaking in the 2007-09 biennium at nearly $4.80 per gallon.

LNG Fuel Price Forecasts – National and State of Washington

National forecasts by the U.S. Energy Information Administration (USEIA) and other independent analysts project a stable and growing source of domestic supply with relative price stability, largely as the result of the discovery of substantial new supplies of shale gas in the Mountain West, the South and throughout the Northeast's Appalachian Basin.

Prices for natural gas, from which LNG prices are derived, are anticipated to remain relatively low compared to ULSD.

Gas utilities operating in Washington State are required to file Integrated Resource Plans (IRP) with the Washington State Transportation and Utilities Commission every two years.

Price forecasts by the five utilities that file an IRP are based on the Henry Hub gas price forecast, which is the one used on the New York Mercantile Exchange. The price forecasts in the 2010-2011 IRPs are lower than in the IRPs filed in 2008-9, reflecting the national trends.

While natural gas prices are more stable than diesel prices, they also experience volatility. Natural gas prices rose in 2000-01 with the energy crisis, in 2005 from the impact of hurricanes Katrina and Rita, and in 2008 with oil speculation and high demand. Major factors that could make future natural gas prices volatile include: difficulties in extracting shale oil, drilling restrictions, and the potential for U.S. policy to encourage the use of natural gas in automobiles.

LNG Supply Facilities

There are three types of LNG facilities that are involved in the supply of LNG: LNG terminals which handle import and export of LNG; liquefaction facilities where natural gas is converted to LNG; and storage facilities where LNG is stored for future use.

There are six liquefaction and/or storage facilities in the Pacific Northwest, all of which are limited to supporting gas utilities. There are no LNG terminals in the Pacific Northwest.

Three options have been identified by those interviewed for this report to supply LNG for WSF needs:

- Participate in the construction and/or operation of a LNG liquefaction and storage facility
- Truck LNG in from outside the Pacific Northwest
- Truck LNG from within the Pacific Northwest

Constructing a liquefaction facility is not a viable option in the short term consideration of LNG fueled vessels because of the costs, schedule implications, and permitting difficulties.

LNG Price Forecast for WSF

The consultants have developed two price forecasts for WSF LNG: the first assumes trucking LNG from outside the Pacific Northwest and the second assumes a Pacific Northwest supplier. If LNG can be obtained from a facility in the Pacific Northwest, it will lower the cost of transportation and provide less supply chain risk than a more distant alternative.

For the forecast assuming trucking from outside the Pacific Northwest, the consultants worked with the Transportation Revenue Forecast Council's Henry Hub long-term natural gas forecast and then worked with Poten & Partners, an energy consulting firm, to develop the base price per gallon, and additional cost factors for liquefaction and transport.

The consultants used pricing information provided by FortisBC, a Canadian supplier of peak shaving natural gas to utilities that is expanding production and delivery capabilities, to develop the forecast for trucking from within the Pacific Northwest. The Henry Hub pricing and other factors from the outside the Pacific Northwest forecast were also used in the trucking from within the Pacific Northwest forecast.

Fuel Savings

Based on the two LNG price forecasts developed by the consultants, retrofitting all six Issaquah class vessels could save between $139.9 million and $195.5 million in fuel costs over the remaining life of the vessels. For a new 144-car vessel the savings range from $86.3 million to $120.0 million over the life of the vessel.

The consultants also considered the potential savings if the three Jumbo Mark IIs could be converted to LNG. The savings range from $355.0 to $494.6 million over the remaining life of these vessels.

LNG VESSEL BUNKERING AND MAINTENANCE

Bunkering

Refueling or bunkering of LNG is a more complex operation than diesel fueling and may require operational adjustments.

On the routes with planned service by an Issaquah class or new 144-car vessel, WSF currently fuels by truck at the Bremerton terminal for the Seattle-Bremerton route, Southworth terminal for the Fauntleroy-Vashon-Southworth route, the Clinton terminal for the Mukilteo-Clinton route, and the Anacortes terminal for all the San Juans routes.

The consultants observed the fueling of vessels in Norway. In Oslo for the Tide Sjo passenger only ferries fueling takes place by truck, the same as the WSF LNG vessels would under current plans. We also observed the fueling of an Issaquah class vessel at Bremerton. The safety precautions, requirements for crew safety attire, and monitoring devices are more sophisticated with LNG than with the current diesel fueling process.

Classification

Classification of operating vessels involves inspections by the classification society to determine if the vessel operation and status are in compliance with applicable rules. WSF does not maintain class on its diesel vessels nor do the Norwegian ferry operators the consultants interviewed for their diesel vessels. The Norwegian ferry operators that were interviewed have maintained class on their LNG fueled vessels because of the relative sophistication of the vessels and limited experience with operating them. The classification society Det Norske Veritas (DNV) has provided an estimated cost of $15,000 per vessel per year for on-going classification services. By maintain classification during operation WSF will have an independent annual assessment of the safety of its LNG vessels.

Maintenance Costs and Crew Staffing

Consultant interviews with Fjord1 in October 2011 and interviews with Tide Sjo in Oslo indicate that maintenance costs for the LNG vessels are now projected to be the same as for their diesel vessels.

The Norwegians are finding that oil changes can be possibly extended to 30,000 service hours from the normal 8,000 service hours because the engine is so clean.

The USCG makes the determination on minimum staffing levels in the United States. The Norwegians have no additional staffing on their LNG vessels when compared to their diesel vessels. This analysis assumes that no changes in staffing levels will be required by the USCG when it issues the Certificate of Inspection.

VESSEL DESIGN AND CONSTRUCTION

Design Regulatory Requirements

There are regulatory differences between diesel and LNG fueled ferries. The USCG has not developed rules governing the design, construction and operation of LNG fueled passenger vessels. This introduces an element of regulatory uncertainty that is not present when designing and building a diesel fueled vessel.

WSF's conceptual design work for the re-design of the new 144-car ferry to use LNG fuel, much of which has been done by their contracted naval architect The Glosten Associates, and for the Issaquah class retrofit is the most advanced design work that has been done in the United States on a LNG fueled passenger vessel. If the new 144-car ferry is built as an LNG fueled vessel or an Issaquah retrofit is undertaken, it will most likely be the first LNG fueled passenger vessel subject to U.S. regulations.

In the absence of specific rules, the USCG can review and approve alternative designs under 46 CFR 50.20-30 - alternative materials or methods of construction. In using its authority under 46 CFR 50.20-30 to review LNG fueled passenger vessels, the USCG is relying on International Maritime Organization (IMO) and, to some extent, Det Norske Veritas (DNV) rules. IMO is also revising its rules for LNG fueled passenger vessels and has extended the deadline for completion of rule changes from 2012 to 2014.

WSF submitted two requests for regulatory review to the USCG: one for the new 144-car vessel and separately, in September 2011, for the Issaquah class vessel retrofit. The USCG has responded to both requests with letters that will serve as a regulatory design basis.

> *The Marine Safety Center (section of the USCG) will use the regulatory design basis letter and applicable regulations and standards to complete plan review. Please note that due to your proposed use of LNG fueled propulsion systems, MSC may identify additional detailed design requirements in areas not addressed in this regulatory review design basis agreement during the course of plan review. As always, the Officer in Charge, Marine Inspection may impose additional requirements should inspection during construction reveal the need for further safety measures or changes in construction or arrangement (USCG July 1, 2011, 144-Auto and December 19, 2011 Issaquah Class)*

Design Considerations

DNV has identified three main safety challenges using LNG as a marine fuel: explosion risk, the low temperature of LNG which can cause cracking if released onto the deck, and the LNG storage tanks which must be protected from external fire, mechanical impact, and from the ship side and bottom in the event of a collision or grounding. Two considerations for WSF if they receive funding for detailed design are the engine room standard to which the ship will be constructed and the location of the storage tanks, which are now planned above deck.

Design Expertise

WSF has discussed the potential for designing the LNG Issaquah class retrofit in-house. For conversion of at least the first Issaquah class vessel, WSF should contract with an outside firm that has specialized expertise in LNG fueled systems design. Washington State naval architectural firms would have to sub-contract with firms that are experienced in the design of LNG fueled passenger vessels to meet the requirements.

Major Conversion

Under USCG rules, if a vessel undergoes a certain level of re-design or change, it may be classified as a "major conversion". If the USCG decides that the Issaquah class retrofit is a major conversion WSF would be required to update the vessel to meet all current regulatory requirements which would add considerable cost.

U.S. Shipyard Experience

No U. S. shipyards have experience with the construction of LNG fueled passenger vessels, which will add risk to the project. WSF should require the shipyard to retain someone with LNG construction experience.

CAPITAL PROJECT COST ESTIMATE

The consultants sub-contracted with an experienced shipyard estimator and consulted with a shipyard in Norway that has experience with constructing new LNG vessels and is retrofitting a vessel that is similar in size to the Issaquah class ferries.

The consultants estimate the cost for the conversion of all six Issaquah class vessels in year of expenditure dollars at $143.6 million, which is 40 percent higher than WSF's estimate of $103.0 million.

The new-144 car vessel cost estimate compares the existing new 144-car vessel design with an adaption of that design to a LNG fueled vessel. The consultants' estimate for the additional cost to construct a new 144-car LNG vessel is $18.9 million, which is 31 percent higher than WSF's estimate of $14.5 million in current dollars. If constructed in the 2013-15 biennium, our estimate is that a new 144-car LNG vessel would cost $20.3 million more than a diesel-fueled new 144-car vessel and the comparable WSF estimate would be $15.5 million.

The WSF and the consultants' cost estimates include the same amount for WSF non-vessel projects or soft costs. These costs were not included in previous WSF estimates. They are:

- *First Issaquah class conversion* - $1.7 million for security planning, training, and replacement service

- *Subsequent Issaquah class conversion* - $0.3 million to $1.0 million depending on whether the *Evergreen State* is used for replacement service
- *New 144-car vessel* - $1.1 million for security planning and training that would be in addition to the diesel fueled vessel.

The difference between the estimates is from:

- *Classification.* The consultants' estimate includes $0.3 million to retain a classification society during construction which is not included in the WSF estimate.
- *Design.* The consultants' estimates assume outside designers for the Issaquah class retrofit as well as the new 144-car LNG vessel. WSF included outside designers only for the new 144-car LNG vessel.
- *Shipyard supervision.* The consultants' estimate assumes greater shipyard supervision from within the yard and the retention of an outside LNG construction expert.

The consultants, based on their interviews in Norway with an experienced shipyard, believe that the LNG project is more complex than WSF anticipates. WSF has based their estimate on the assumption that the project is comparable to other motor replacement projects.

CONCLUSIONS AND RECOMMENDATIONS

The consultants' conclusions and recommendations are outlined by policy question below.

<table>
<tr><th>Consultants’ Conclusion</th><th>Consultants’ Recommendations</th></tr>
<tr><td colspan="2">What, if any, impact will the conversion to LNG fueled vessels have on the WSF Alternative Security Plan?</td></tr>
<tr><td>Security and operation planning with its associated public outreach should be the next step in the consideration of LNG for WSF vessels. A final legislative decision on LNG fuel should not be made until this planning is sufficiently complete to: 1) assess the impact of LNG on the Alternative Security Plan and on WSF and Washington State Patrol staffing; and 2) gauge public reaction.</td><td>Recommendation 1. Security and Operational Planning Funding
The consultants recommend that the Legislature provide funding for security and operational planning and the associated public outreach of $1.0 million in the FY 2013 budget.</td></tr>
<tr><td colspan="2">What are the implications of LNG for the vessel acquisition and deployment plan?</td></tr>
<tr><td>The decision whether to build a new 144-car vessel as a LNG fueled vessel should not be made until the security planning is complete. Assuming funding in FY 2013, the security planning could be completed by January 1, 2014 at which point a decision could be made on whether to proceed with the new 144-car vessel as a LNG fueled vessel. If funded in FY 2014, the new 144-car LNG vessel could potentially come on line in 2017.
A new 144-car LNG vessel should be purpose built as a LNG vessel. The most economical action would be to consider the first new 144-car LNG vessel as part of a series of six such vessels or so many as the Legislature decides to fund. This would allow WSF to acquire a purpose built LNG design. A purpose built design would result in safety improvements from the engine room being designed specifically for LNG. It would also allow WSF to achieve the economies of scale of purchasing more than one vessel at a time.
Retrofitting the Issaquah class ferries will take at least six years and require the Evergreen State to stay in service unless a second new 144-car vessel comes on line. Under the most aggressive schedule the retrofitted Issaquah class vessels would come on line between 2015 and 2020. The Evergreen State would have to remain in service past its projected 2014 retirement for up to six additional years at which point it will be 66 years old. Funding for preservation of the Evergreen State is not included in the 2011-27 16-year financial plan because it is expected to retire.</td><td>Recommendation 2. New 144-Car Vessel
The consultants recommend that the Legislature proceed with construction of the second new 144-car vessel as a diesel fueled vessel, with delivery in 2015 if funding is available, if it is more important to improve service on the schedule anticipated in the WSF Long-Range Plan than to potentially reduce operations costs. If the Legislature considers construction of a LNG fueled vessel it should consider the investment only after the completion of security planning and in the context of the planned procurement of five new 144-car vessels to allow for the acquisition of a purpose built LNG design and potential economies of scale in ship building.
Recommendation 3. Issaquah Class Retrofit
If the Legislature considers retrofitting the Issaquah class vessels, it should do so only after the completion of security planning. Design and construction should follow recommendations 4-7 below. The legislature should also recognize that funding will need to be provided for preservation of the Evergreen State estimate an additional $0.4 million until 2018, at which point it would potentially need propulsion controls replaced at a cost of $5.7 million.</td></tr>
</table>

Consultants' Conclusion	Consultants' Recommendations
What design and construction constraints should be considered in making LNG decisions?	
• **Safety in the design and construction of LNG vessels is of paramount importance.** Other nations, particularly Norway, and the classification societies can help overcome the lack of U.S. experience with LNG fueled passenger vessel design and construction. If a vessel is constructed to class it means that the classification society guidelines have been followed and the classification society has inspected the construction and certified it. This is in essence a quality inspection. • **The pre-design process will allow the Legislature to review the design options before making a final decision.** The Legislature requires that all vessel improvement projects and vessel preservation projects over $5 million include a pre-design study (ESHB 3209 adopted in the 2010 session). The pre-design study can provide the Legislature with additional information prior to appropriating funds for construction of a LNG fueled vessel. • **A major conversion decision should be sought from the USCG prior to starting construction.** If the USCG decides that the Issaquah class retrofits are major conversions, it could make the retrofit prohibitively expensive because the vessel would be required to meet all USCG equipment and ADA regulations as if it were a new build.	**Recommendation 4. Design** If the Legislature decides to pursue a LNG fueled vessel, the Legislature should provide funding and require WSF to: • Contract with an outside design firm that has previous LNG fueled passenger vessel design experience rather than design the LNG vessels in-house. As a practical matter, Washington state naval architects would have to sub-contract with firms that are experienced in the design of LNG fueled systems to meet this requirement • Design LNG vessels to a classification society rules (which could be DNV or another classification society) and have them classed during construction. **Recommendation 5. Construction** The Legislature should consider amending the bid process to require bidders to include an expert from a shipyard with LNG fueled vessel construction experience in their bid that WSF could qualitatively evaluate. **Recommendation 6: Regulatory Determination for Issaquah class retrofit** WSF should request a ruling from the USCG on whether the Issaquah class retrofits will constitute a major conversion before proceeding with more detailed design and construction. **Recommendation 7. Construction** The LNG fuel supply contract should be in place before the shipyard construction contract is let. This will allow the engine to be tested with the actual LNG fuel that will be used in operation and ensure supply and price.

Consultants' Conclusion	Consultants' Recommendations
How will LNG fueled vessels affect bunkering and other WSF operations?	
• **Bunkering will be more complex than diesel but this should not pose a problem for WSF other than requirements that may be part of the security plan.** Bunkering is more complex but with adequate training WSF should be able to accommodate it. However, bunkering requirements may also be a part of the safety plan and those requirements may add additional costs that cannot yet be anticipated. • **Maintenance and staffing costs should be the same as for the diesel-fueled vessels.** This is consistent with the experience in Norway. However, staffing costs may change when the USCG issues the Certificate of Inspection. • **The cost of classification services at $15,000 per year per vessel would be a worthwhile investment.** Maintaining classification services for LNG vessels will help ensure safe operation.	**Recommendation 8. Operation Classification** WSF should maintain classification services for the operation of their LNG vessels during at least the first 10 years of operation**.**
What is the most cost-effective scenario to introduce LNG fueled vessels to the WSF fleet considering both operation cost savings and capital project costs?	
• **The security planning and outreach costs for LNG are substantial and the more vessels these costs cover the more cost effective the investment will be.** The financial analysis is independently done for the Issaquah class retrofit and for the new 144-car vessel. But the one-time costs for security planning will not be repeated if both projects are done or if the Legislature eventually funds more LNG fueled vessels. • **The Issaquah class retrofit is not a sound economic investment as the project is now structured.** Although the economic viability of the Issaquah class retrofit will depend largely on the final design and the USCG major conversion decision, it would be more viable after a second new 144-car vessel is on line. Having a second new 144-car vessel would mean that the retrofit project would not include operating costs of the *Evergreen State*. • **The investment in a new 144-car LNG vessel is economically viable.** The investment would be even better if it is done for a class of LNG vessels with the consequent economies of scale from purchasing more than one vessel at a time.	**Recommendation 9. Pre-Design and Business Case Funding** At the same time WSF is engaged in security planning, the Legislature should provide funding for WSF to develop a more refined business case and pre-design report for the LNG conversion which would consider the potential to retrofit the Jumbo Mark II vessels and provide updated CNG information.

Consultants' Conclusion	Consultants' Recommendations
• **It would be worthwhile to invest in an exploration of the potential retrofit of the Jumbo Mark IIs.** The potential fuel savings are sufficiently large to justify the cost of developing a concept design to see if the Jumbo Mark IIs can be retrofit. • **Development with CNG should be tracked to see if it becomes a viable option for marine fuel for WSF.**CNG may have some advantages that should be considered including a local supply and potentially less hazardous operation. However, the operational implications of daily fueling would have to be considered.	

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INTRODUCTION

Washington State Ferries serves 22.6 million riders on 10 routes in Puget Sound and the San Juan Islands with a fleet of 22 diesel fueled vessels. WSF operation and capital finances are a significant concern to the Legislature, a concern that has been exacerbated by rising fuel prices.

Liquefied natural gas (LNG) provides an opportunity to significantly reduce WSF fuel costs, which in the 2011-13 biennium are $135.2 million or 29 percent of WSF operation costs. LNG can also have a positive environmental effect by eliminating sulfur oxide and particulate matter emissions and reducing carbon dioxide and nitrous oxide emissions from WSF vessels.

This report recommends that the Legislature consider transitioning from diesel fuel to liquefied natural gas for WSF vessels, making LNG vessel project funding decisions in the context of an overall LNG strategic operation, business, and vessel deployment and acquisition analysis that addresses:

- *Security.* What, if any, impact will the conversion to LNG fueled vessels have on the WSF Alternative Security Plan?
- *Vessel acquisition and deployment plan.* What are the implications of LNG for the vessel acquisition and deployment plan?
- *Vessel design and construction.* What design and construction constraints should be considered in making LNG decisions?
- *Vessel operation.* How will LNG fueled vessels affect bunkering and other WSF operations?
- *Business case.* What is the most cost-effective scenario to introduce LNG fueled vessels to the WSF fleet considering both operation cost savings and capital project costs?

This report addresses these questions to the extent that they can be addressed at this stage in planning.

The greatest unknown is the security question, the answer to which will require completion of a U.S. Coast Guard security planning process. The business case, vessel acquisition and deployment, and vessel operation planning may change depending on the outcome of security planning.

SECTION I. PURPOSE AND APPROACH

A. PURPOSE

The 2011 Legislature directed the Joint Transportation Committee to investigate the use of liquefied natural gas (LNG) on existing Washington State Ferry (WSF) vessels as well as the new 144-car class vessels and report to the Legislature by December 31, 2011 (ESHB 1175 204 (5)); (Chapter 367, 2011 Laws, PV).

The JTC Identified the following areas for inclusion in the study: (1) assess WSF's work and studies on LNG use; (2) identify the full range of issues that must be addressed to successfully implement LNG use; and (3) analyze the cost, risk, timeline, and related implications of implementing LNG use for a retrofit of an existing Issaquah class vessel and for incorporating LNG into the new 144-car vessel design. The report is intended to address legislative concerns regarding the full potential cost of LNG, which is less expensive and its price less volatile than the ultra low sulfur diesel (ULSD) currently used by WSF, but may result in other significant costs.

B. APPROACH

This report relies on information available from WSF's studies, the consultants' research and interviews with outside agencies and experts, and consultations with Norwegian vessel owners and a Norwegian shipyard.

WSF documents that have been reviewed include:

- LNG Use for Washington State Ferries March 2010
- 144-Car Ferry LNG Fuel Conversion – Regulatory Review of Concept – May 2011
- 144-Car Ferry LNG Fuel Conversion Feasibility Study – July 2011
- 144-Car Ferry LNG Fuel Conversion Feasibility Study – Life Cycle Cost Analysis – July 2011
- The Use of LNG as a Fuel on the Issaquah Class Passenger Ferries in Puget Sound – Sept. 2011
- Vessel fuel consumption reports – 2009 and 2010

The consultants also reviewed the following reports by others:

- California Energy Commission, West Coast LNG Projects and Proposals, June 2011
- Danish Ministry of the Environment, Natural Gas for Ship Propulsion in Denmark – Possibilities for Using LNG and CNG on Ferry and Cargo Routes, 2010
- Fjord1 Group, Fjord1's Experience with LNG Fueled Ships, 2010
- DNV, Greener Shipping in North America, Feb. 2011
- DNV, LNG as Fuel for Ship Propulsion, Nov. 2010
- Integrated Resource Plans – filed with the Washington State Utilities and Transportation Commission
    - Puget Sound Energy
    - NW Natural
    - Avista
    - Cascade Natural Gas
    - PacifiCorp
- MIT, The Future of Natural Gas, 2011

- Norwegian Marine Technology Research Institute and Norwegian Maritime Directorate, The Norwegian LNG Ferry, 2000
- Northwest Gas Association, Natural Gas Infrastructure in the Pacific Northwest, 2010
- The University of Texas at Austin, Introduction to LNG, January 2007
- United States Department of Homeland Security, United States Coast Guard, The Chesapeake Bay Liquefied Natural Gas Operations Management Plan, May 5, 2006
- United State Energy Information Administration 2011 Energy Outlook and web site materials
- United States Environmental Protection Agency, Global Trade and Fuels Assessment – Additional ECA Modeling Scenarios, May 2009
- Washington State Department of Commerce, Washington Natural Gas Supply, Sept. 2005
- Washington State Department of Commerce, 2004 Natural Gas Study, 2004.

Interviews were conducted with:

- Air Products
- American Strategic Group
- BC Ferries
- Clean Energy
- FortisBC
- Phoenix Public Transit
- Puget Sound Energy
- Shell Oil
- United States Coast Guard
- Vista Natural Gas
- Williams Northwest Pipeline
- World CNG

In Norway the consultants meant with representatives of:

- Fjord1
- Gasnor
- STX Langstein
- Tide Sjo

SECTION II. GLOSSARY

Auto-refrigeration: The process in which LNG is kept at its boiling point, so that any added heat is countered by energy lost from boil off.

Boil off: A small amount of LNG evaporates from the tank during storage, cooling the tank and keeping the pressure inside the tank constant and the LNG at the boiling point. Rise in temperature is countered by LNG being vented from the storage tank.

Btu - British thermal unit: The Btu is the standard unit of measurement for heat. A Btu is defined as the amount of energy needed to raise the temperature of one pound of water one degree Fahrenheit from 58.5 to 59.5 degrees under standard pressure of 30 inches of mercury.

Bunkering: Act or process of supplying a ship with fuel.

Cf - Cubic Foot: A unit of measurement for volume. It represents an area one foot long, by one foot wide, by one foot deep. Natural gas is measured in cubic feet, but the measurements are usually expressed in terms of MMcf (million cubic feet), Bcf (billion cubic feet), Tcf (trillion cubic feet), or Quads (quadrillion cubic feet).

Class Notation: Assigned to vessels in order to determine applicable rule requirements for assignment and retention of class. Vessels can be built to class only or built and maintained in a class.

Compression: Natural gas is compressed during transportation and storage. The standard pressure that gas volumes are measured at is 14.7 Pounds per Square inch (psi). When being transported through pipelines, and when being stored, gas is compressed to save space.

CNG - Compressed Natural Gas: Natural gas in its gaseous state that has been compressed between 2600 and 3900 psi.

Cryogenic Liquid or Cryogens: Cryogenic liquids are liquefied gases that are kept in their liquid state at very low temperatures and have a normal boiling point below -238 degrees Fahrenheit (-150 degrees Celsius). All cryogenic liquids are gases at normal temperatures and pressures. These liquids include methane, oxygen, nitrogen, helium and hydrogen. Cryogens normally are stored at low pressures.

Deliverability Rate: A measure of the amount of gas that can be delivered (withdrawn) from a storage facility on a daily basis, typically expressed in terms of millions of cubic feet per day (MMcf/day).

Emissions Control Area (ECA): Designated by International Maritime Organization (IMO) as areas that must reduce fuel sulfur and emissions beyond global standards. The North American ECA will extend 200 miles off the US coast and tiered implementation will begin in 2012.Beginning in 2015, fuel used by all vessels operating in these areas cannot exceed 0.1 percent fuel sulfur (1000 ppm). This requirement is expected to reduce PM (particulate matter) and SO_x (sulfurous oxides) emissions by more than 85 percent. Beginning in 2016, new engines on vessels operating in these areas must use emission controls that achieve an 80 percent reduction in NO_x (nitrous oxides) emissions.

FERC - Federal Energy Regulatory Commission: The federal agency that regulates interstate gas pipelines and interstate gas sales under the Natural Gas Act. The FERC is considered an independent regulatory agency responsible primarily to Congress, but it is housed in the Department of Energy.

Hydrocarbon: An organic compound containing only carbon and hydrogen. Hydrocarbons often occur in petroleum products, natural gas, and coals.

Liquefaction: The process by which natural gas is converted into liquid natural gas.

Liquefied Natural Gas (LNG): Natural gas (predominantly Methane, CH_4) that has been cooled to -259 degrees Fahrenheit (-161 degrees Celsius) and at which point it is condensed into a liquid which is colorless, odorless, non-corrosive and non-toxic. Characterized as a cryogenic liquid.

Liquefied Petroleum Gas (LPG): Gas consisting primarily of propane, propylene, butane, and butylene in various mixtures. Stored as a liquid by increasing pressure.

MMcf: A volume measurement of natural gas; one million cubic feet.

MMtpa: Million tons per annum - one ton (or metric ton) is approximately 2.47 cubic meter of LNG.

Peak-Shaving: Using sources of energy, such as natural gas from storage, to supplement the normal amounts delivered to customers during peak-use periods. Using these supplemental sources prevents pipelines from having to expand their delivery facilities just to accommodate short periods of extremely high demand.

Peak-Shaving Facility: A facility which stores natural gas to be used to supplement the normal amount of gas delivered to customers during peak-use periods.

Regasification: The process by which LNG is heated, converting it into its gaseous state.

Storage Facilities: Facilities used for storing natural gas. These facilities are generally found as gaseous storage facilities and liquefied natural gas (LNG) storage facilities.

Ultra Low Sulfur Diesel: Ultra Low Sulfur Diesel is the primary highway diesel fuel produced. ULSD is a cleaner-burning diesel fuel that contains 97% less sulfur than low-sulfur diesel (LSD). ULSD was developed to allow the use of improved pollution control devices that reduce diesel emissions more effectively but can be damaged by sulfur.

SECTION III. LNG AS MARINE FUEL

This section reviews the use of LNG as a marine fuel. Norway is the world leader in LNG fueled passenger vessels and today operates the only LNG fueled ferries in the world. The consultants met with representatives of Norwegian ferry operators Fjord1 and Tide Sjo and with a Tide Sjo's LNG supplier Gasnor. A summary of findings is included in this section.

This section also provides an overview of three North American ferry operators who are considering LNG: BC Ferries, Staten Island Ferries, and the Quebec Ferries Company. The Quebec Ferries Company has ordered three LNG ferries.

Compressed natural gas (CNG) has been used only infrequently as a marine fuel primarily because LNG is more volume-effective, with LNG requiring approximately two times the fuel volume of oil and CNG approximately five times. Interviews with two companies interested in supplying CNG to WSF as a marine fuel are included in this section.

A. Liquefied Natural Gas

Liquefied natural gas (LNG) is natural gas that has been cooled to -259 degrees Fahrenheit at which point it is condensed into a liquid, which is colorless, odorless, non-corrosive, and non-toxic. LNG is a cryogenic liquid meaning that it must be kept cooled to -259^{o} F or it returns to its gaseous state.

LNG takes up about 1/600th of the volume of natural gas in the gaseous state. This makes it cost efficient to transport in specially designed cryogenic LNG carriers over long distances opening up market access to areas where pipelines do not exist and/or are not practical to construct.

B. LNG Carriers

The first LNG carrier began service in 1959 with a shipment from Lake Charles, Louisiana to the United Kingdom. Beginning in 1964 LNG carriers began using the boil-off of LNG as the fuel source for the vessel's propulsion system. (A small volume of LNG is naturally boiled off to keep the bulk of the LNG in its liquid form.) All current LNG carrier vessels use this method of fueling, which is not available for any other type of vessel.

There are approximately 300 LNG carrier vessels worldwide – none of which are U.S. flagged.

C. LNG Ferries in Norway

Norway is the world leader in LNG fueled passenger vessels and today operates the only LNG fueled ferries in the world.

1. History of LNG Fueled Ferries in Norway

The discovery of large quantities of natural gas on Norway's west coast in 1997 allowed LNG to be available at an acceptable cost for ferry operation to be feasible. Before this discovery, Norwegian studies started in 1989 had concluded natural gas ferries were not cost effective.

The Norwegian government decided in 1997 to build two types of gas-operated car and passenger ferries; one operating on LNG and one on compressed natural gas (CNG). The CNG project was never started.[1]

Beginning in 1997 the Norwegian equivalent to the Coast Guard, the Norwegian Maritime Directorate, spent three years with a task force that included ferry operators, other public agencies and consultants developing regulations for LNG fueled passenger ships after some initial concerns about their safety were satisfied by studies and calculations. The issues that needed to be resolved for gas engines included:

- Reducing the risk of explosion in areas where gas was held
- Redundancy of fuel storage, power generation, transmission and propellers
- Separation of engines into two engine rooms and fuel supply
- Double piping of all gas pipes
- No danger to passenger life in case of fire or explosion and ability of the ship to get to port
- Detection of gas leakage in all areas where gas is in place.

The first Norwegian LNG ferry, Fjord1's *Glutra,* was built in 2000 with government assistance. The ferry, which was built to carry 100 cars and 300 passengers, cost 30 percent more than a comparable diesel powered vessel. This cost was thought to be acceptable given the fact that the knowledge gained in its construction would bring down the cost of ensuing LNG ferries.[2]

2. Norwegian LNG Ferries - 2011

In 2011, Fjord1 has 12 LNG ferries operating in Norwegian waters and more under construction. The *Glutra* was lengthened in 2010 and now accommodates 182 cars and 350 passengers. Other Norwegian ferry operators also have LNG ferries including: Tide Sjo which has three; and Fosen Namos Sjo which has one. Another operator, Torghatten Nord, is undertaking a program to build three new LNG ferries and convert four existing vessels to LNG.

3. Tide Sjo and Fjord1Experience

The consultants met with representatives of Fjord1,Tide Sjo, and Gasnor, an LNG supplier, in Norway. Fjord1's experience with LNG ferries was also summarized in a presentation by their Operations Manager at the Ferries 2010 Conference in Seattle in November, 2010.[3]

a. Fjord1

Fjord1 was formed in 2001 after the merger of two parent companies. Fjord1 has a total of seven subsidiaries that handle sea, bus, and freight services. Ferries are operated throughout the coastal regions of Norway by a fleet of over 60 vessels, including 12 LNG auto-passenger ferries. Fjord1, like Tide Sjo and other Norwegian operators, is a private company that operates ferry service for the government on a contractual basis.

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[1] Oscar Bergheim, Operations Manager Fjord1 Fylkesbaatane, presentation at Ferries 2010 Conference in Seattle, WA November 2010.

[2] Per Magne Einang and Konrad Magnus Haavik, *The Norwegian LNG Ferry*, Norwegian Marine Technology Research Institute and the Norwegian Maritime Directorate, Paper A-095 NGV 2000 Yokohama.

[3] Oscar Bergheim, "Fjord1's Experience with LNG Fueled Ships" presentation at Ferries 2010 Conference, Seattle WA. Nov. 2010.

b. Tide Sjo

Tide Sjo is a 160-year-old Norwegian transit operator that operates buses and ferries throughout Norway. Since 2009, Tide has operated the passenger ferry service between Oslo and Nesodden. There are currently three 600-passenger LNG ferries operating out of central Oslo. The municipal government mandated LNG operation as part of the contract for the service over this route and Tide won the 15-year contract with two five-year options at the end. Tide Sjo receives a monthly subsidy as part of this contract and in turn is responsible for all operational and capital costs.

c. Gasnor

Gasnor is one of two Norwegian LNG suppliers. It was established in 1989 and made its first gas delivery in 1994. Gasnor is owned by a conglomeration of six energy companies and serves a diverse set of customers in industry, transportation, and a residential distribution network in Karmoy, Norway. They operate 3 LNG production plants, 16 LNG semitrailer delivery trucks, 13 CNG semitrailers, 30 terminals, and 2 coastal LNG supply tankers. Total production capacity is 300,000 tons a year and 50,000 deliveries have been made without incident.

d. Summary of Findings

This is a summary of the findings from Fjord1, Tide Sjo, and Gasnor. Additional information is provided at the appropriate section in the remainder of this report.

- *Capital cost.* The cost of building the LNG ferries is 15-20 percent higher than diesel ferries. DNV, the classification society, notes that "New ships with LNG propulsion typically have an added investment cost of 10-20 percent. The additional cost is mainly due to the sophisticated LNG storage tanks, the fuel piping system, and in some cases a slightly larger ship."[4]
    - *Capital subsidy.* Norwegian ferry operators are eligible for a subsidy of up to 80 percent of the cost for projects that reduce NOx emissions from the NOx Foundation. These projects can include the cost differential of LNG vs. diesel construction, which for Tide Sjo were about $3.6 million per ship.
- *Carbon tax credits*. Norwegian ferry operators are able to avoid carbon taxes on natural gas that is used in lieu of diesel, which lowers the operations cost for LNG fueled vessels.
- *Maintenance and operation cost*. Fjord1 and Tide Sjo state that while maintenance costs were higher on the first LNG vessels they are now comparable between the two types of vessels.[5] Maintenance issues on the LNG ferries have included "black outs," or engine room shutdown, due more to human than technical error; three instances of pipe leakage due to poor welding, and some issues with the thrusters but close to none with the main engines.
- *Crew size and training.* Crew size is the same as on the diesel-powered ferries. Crew training for Fjord1 includes a gas course including risk aspects, emergency shutdown (ESD) philosophy, gas engine operation, and demonstration of gas explosions. The course takes two to five days, and the instructors are from the company. The remainder is familiarization training conducted on board the vessel. An officer needs about one week training before being on duty. All Tide Sjo crew members on the LNG powered ferries must take a two-day gas training course then go

[4] DNV, *Greener Shipping in North America*, February 2011, p. 10.
[5] Oscar Bergheim's 2010 presentation "Fjord1's Experience with LNG Fueled Ships" stated that normal maintenance costs of the Glutra have been 20 percent higher than a similar-sized diesel vessel and maintenance costs of its five (5) sister ships in operation since 2007 have been 10 percent higher. Interviews in Norway indicate that maintenance costs are now believed to be the same.

through familiarization on the vessel before taking part in the bunkering process. There is a four-person crew consisting of a captain, chief engineer, and two deckhands and all four take part in the bunkering process. In addition, the LNG truck driver takes part in the bunkering process.

- *Cost of LNG.* The cost of natural gas in Norway has been close to, or slightly above, diesel and the energy cost to operate the LNG ferries has been slightly higher than diesel ferries. The cost of natural gas and diesel rise and fall together in Norway, which has not been the case in the United States. See Appendix A for further information.
- *LNG Supply.* The LNG used by the three Tide Sjo vessels is delivered from Bergen, a 322 mile drive, the longest distance Gasnor delivers LNG with their fleet of 16 supply trucks. They also have supply vessels that deliver LNG to coastal facilities. The official from Gasnor noted several key points for the supply:
    - *Testing.* It is important to test the vessel engines with the LNG that will be used, as the gas composition varies by source. These three vessels were built in France and they brought LNG from Norway to test the engines.
    - *Shoreside fixed fueling facilities and tanks*. Shoreside fixed fueling facilities can save money and ease concerns about on-time delivery, but it only make sense if there is enough LNG consumption to justify the capital expense. In the case of Tide Sjo, there is not enough LNG consumption to justify such an infrastructure expense and the vessels do not need to be refueled often.
    - *Contracts*. Gasnor generally enters into long-term 7-10 year contracts that have a fixed side that adjusts with the consumer price index and a commodity side that adjusts with the fluctuations in gas price.
- *Environmental impact.* The LNG vessels have been successful in reducing CO_2 emissions by 19 percent, NO_x by 91 percent, and SO_x and particulate matter by 100 percent. [6]
- *Security planning and community outreach.* Security planning is much less elaborate than will be required in the United States. Tide Sjo officials indicated no significant public outreach effort regarding safety was needed. Gasnor, their LNG supplier, led the safety planning, which consisted of a four-hour planning meeting with local fire and police officials to develop an emergency response plan.
- *Vessel design.* All of Tide Sjo and Fjord1's LNG fueled ferries are built to emergency shutdown (ESD) standards for the engine room and have the LNG storage tanks below deck.

D. Other LNG Fueled Passenger Vessels

The world's largest LNG fueled passenger ship is currently being constructed for the Viking Line system that operates in Finland, Norway, and the Baltic countries. The vessel will be a cruise liner with capacity for 2,800 passengers, 200 crew, 1,300 lane meters for trucks, and 500 lane meters for cars. The vessel will operate on a relatively short route between Stockholm and Turku, Finland, allowing it to be refueled with LNG. It is scheduled for delivery in 2013.

A high speed LNG catamaran is currently under construction in Australia and will go into service next year between Buenos Aires and Montevideo. The ship will be dual-fuel, capable of operating on LNG or diesel; have capacity for 153 vehicles and 1,000 passengers; and be capable of speeds up to 50 knots.

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[6] Oscar Bergheim, "Fjord1's Experience with LNG Fueled Ships."

E. Other LNG Fueled Vessels

There are no American flagged LNG vessels. Glosten Associates did the design for a pilot LNG-powered tug for Crowley Maritime in the Los Angeles Harbor but the project remains on hold due to cost concerns. Norway has three LNG fueled vessels built for their Maritime Directorate, the equivalent of the USCG and four LNG fueled off-shore supply vessels.

F. Other North American Ferry Systems

The consultants contacted several other North American ferry systems to see if they are considering LNG fueled ferries. The three currently considering LNG for ferries are the Staten Island Ferry system, BC Ferries, and Société des traversiers du Québec (STQ) in Québec.

- *Staten Island Ferry (New York City)*. The Staten Island Ferry system has received a $2.3 million federal grant to study LNG retrofit of an existing ferry.
- *BC Ferries*. The consultants and WSF staff held a conference call with BC Ferries officials. BC Ferries is conducting a feasibility study of converting the 85-car *Queen of Capilano* to LNG, with hopes of expanding the conversions to other existing vessels, including the 410-auto Spirit class vessels, and new construction. CNG was not considered a viable fuel source due to the volume needed. Officials noted the two vessels that used CNG in Canada before were smaller vessels for a river crossing and were later converted back to diesel. BC Ferries staff believe their biggest challenge will be the potential public reaction to LNG. They are working closely with a potential Canadian supplier of LNG, FortisBC, on a public outreach and communications plan to help alleviate fears about the use of LNG in communities surrounding the bunkering of the fuel, which they plan to do onboard via truck delivery. They are in discussions with the classification society American Bureau of Shipping and Transport Canada (equivalent of the USCG) regarding regulatory approval and do not currently foresee it being a major obstacle.
- *Société des traversiers du Québec (STQ*). La Société des Traversiers du Québec (the Quebec Ferries Company) is purchasing three LNG ferries: two to ply the Tadoussac/ Baie-Sainte-Catherine Saguenay River fjord about 100 miles northeast of Quebec, and one for the Matane and Baie-Comeau/Godbout crossing even farther east, at the mouth of the St. Lawrence River. The new boats will have dual-fuel engines by Wärtsilä with delivery slated for fall 2013 and spring 2014. Fuel will be supplied via LNG tanker trailers operated by Transport Robert – using LNG tractors if logistics allow. A third new LNG ferry for the Matane–Baie-Comeau–Godbout crossing in eastern Canada will hold 800 passengers and 180 automobiles.
- *North Carolina Ferries*- LNG retrofit is too expensive to implement on their older ferries and no new LNG ferries are being considered. North Carolina Ferries is concerned about other regulatory impacts on older ferry conversions.
- *Woods Hole (Massachusetts).* Their new 64-car vessels (the Island Homes) are the basis for the design of WSF's Kwa-di Tabil class ferries. The vessels are too new to consider retrofitting them and Woods Hole is concerned about stability and draft. Their older ferries are too old to justify the investment. They are also concerned about the supply of LNG and uncertain about the public reaction.
- *Cape May (New Jersey).* Cape May had some interest, but do not have enough funding to explore LNG. They are looking at new high speed ferries that are not suitable for LNG due to space considerations.
- *Maine State.* Not considered.
- *Alaska Marine Highways.* Not considering at this time.

G. LNG Retrofits

All of the current Norwegian LNG ferries were new construction. Fjord1 is retrofitting a 20-year old vessel at the end of this year at an estimated cost of 8 million euro and Torghatten Nord has plans to convert three vessels to LNG. The reasons why vessels are seldom retrofitted include:

- *Vessel life.* Most vessels are assumed to have a life of 30 years rather than the 60 years that WSF projects. As a consequence of the shorter remaining life of a vessel there is less time to amortize the investment.
- *Impact on car space or other economics.* In some instances vessel owners have decided against a retrofit because in Europe the fuel tanks are in the vessel's hold. LNG requires more volume for the same energy output than diesel and as a consequence vessel owners face the possibility of losing car space because of the additional space needed for the larger fuel storage tanks.

H. LNG Emissions

In Norway the primary impetus to have LNG fueled ferries is the reduction in emissions. LNG will also provide improved emissions control for WSF, even beyond those required by the new North American Emissions Control Area. The International Maritime Organization formed the North American Emissions Control Area in 2010. The control area requires ships operating up to 200 nautical miles off the North American coast to meet more stringent fuel sulfur content requirements than are required in non-ECA waters. It also provides for progressively more stringent requirements for nitrogen oxide (NO_x), which are achieved by requiring more efficient engines.

WSF's use of ULSD means that it is already in compliance with the North American Emissions Control Area requirements. LNG will provide emissions control beyond these requirements. "The environmental qualities of LNG are superior to those of any liquid petroleum fuel. The use of LNG effectively eliminates the need for exhaust gas after-treatment, due to very low NO_x formation in the engines, as well as the absence of sulfur."[7] The table below shows the LNG emission comparison to the ULSD used by WSF.

Exhibit 1.
LNG Emission Comparison
(g/kWh)

Fuel Type	Sulfur Oxide	Nitrous Oxide	Particulate Matter	Carbon Dioxide
Marine ultra low sulfur diesel oil, 0.1%	0.4	8-11	1.5	580-630
LNG	0	2	0	430-482

Source: Boylston, John LNG as a Fuel Source for Vessels – Some Design Notes

I. Compressed Natural Gas (CNG) Fueled Vessels

1. CNG as a Marine Fuel

When the LNG ferry *Glutra* was built in Norway the intent of the Norwegian government was to also construct a CNG vessel. The CNG vessel project did not proceed.

A 2010 study by the Danish Ministry of the Environment considered the possibility of using LNG and CNG on ferry and cargo routes. The study notes that the primary disadvantage of CNG when compared to

[7] Boylston, John, *LNG as a Fuel for Vessels – Some Design Notes,* p. 2.

LNG is that LNG is more volume-effective. "LNG requires approximately 2 times the fuel volume of oil, and CNG (at 200 bar) requires 5 times the volume of oil."[8] As a consequence the tanks on CNG fueled vessel would have to be much larger to get the same distance as an LNG fueled vessel and/or the vessel would have to re-fuel more frequently.

The Danish study identified three small ferries that are fueled by CNG. These ferries are not comparable to the new 144-car vessel or the Issaquah class ferries operated by WSF.

- *Vancouver B.C. Translink.* Two of the CNG ferries were operated in Vancouver B.C. These K-class ferries carried 26 cars and 146 passengers and were refueled twice a day using about 3-4 minutes each time. The *Kullee*t and the *Klatawa* operated by the Albion Ferry on the Fraser River until July 31, 2009, when the Golden Ears Bridge opened and the ferry route was discontinued. Before their retirement and subsequent sale the ferries had been re-converted to diesel.
- *Virginia Paddlewheel Passenger-Only Ferry.* The Elizabeth River Ferry system has three paddlewheel vessels, each of which accommodates 150 passengers for a five minute trip. One of the vessels is CNG powered.

There are five other small pleasure or tourist boats in the world that operate on CNG and one (1) cargo ship, a limestone carrier built to operate in the coastal waters of Australia.

Given the relative scarcity of CNG fueled vessels, the Danish study noted that "for CNG the development of the shipping sector appears not to have progressed much over the last decade" with, relative to LNG a lack of developed technology. As a consequence the study concluded, "LNG will presumably be the de facto choice at least for 5 – 10 years over CNG.[9]

2. CNG Potential for WSF

There is however reason to believe CNG could be a viable option for WSF vessels in the future. The consultants met with representatives of two local companies, Vista Natural Gas and American Strategic Group, regarding the potential for CNG to fuel WSF vessels. Two aspects of CNG make it worthy of consideration for WSF: 1) a gas pipeline connected CNG plant is being completed just south of Tacoma, providing a closer, more assured delivery to WSF ferries than is presently possible from LNG sources; and 2) while the volume requirement for CNG is greater and often discounted for marine vessels because of space limitations, a daily fueling would allow the tanks to be about the same size as the proposed LNG tanks. Fueling could be done while the ferries are idle nightly, but the impacts on crew, who may be required to monitor the process instead of accomplishing other tasks, would need to be examined.

The advantages of CNG are that it is a non-cryogenic product and does not have the potential to create a vapor when released. Unlike LNG, if released CNG will not create brittle fractures in steel, has less hazardous fueling procedures, the storage and distribution systems onboard the vessel are less costly, and permanent fueling stations are less costly and may be easier to permit. The disadvantages of CNG, in addition to the volume requirements, are that it is also a highly compressed gas and hazardous to carry, fueling requires compression and is not as efficient as LNG with a great deal left in the tank, and fueling for equivalent energy amounts would take longer than for LNG.

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[8] Litehauz, IncentivePartners, DNV, and Ramboil Oil & Gas*, Natural Gas for Ship Propulsion in Denmark – Possibilities for Using LNG and CNG on Ferry and Cargo Routes,* Danish Ministry of the Environment, 2010, p. 27.
[9] Ibid., p. 9-12.

SECTION IV. SECURITY AND OPERATION PLANNING

Security and operation planning and the associated public outreach are critical to WSF's ability to operate LNG fueled vessel.

The security planning process anticipated by WSF is a modified version of the process the United States Coast Guard (USCG) uses for the review of waterfront liquefied natural gas facilities. The process is outlined in the USCG's Navigation and Vessel Inspection Circular (NVIC) No. 01-2011 Guidance Related to Waterfront Liquefied Natural Gas Facilities and would be coordinated by the USCG. The process will allow inter-agency coordination between federal, state, and local public safety officials, encompass the entire WSF service area, and can include stakeholders such as members of the public and/or representatives of the Ferry Advisory Committees.

WSF has said they will support the security planning process with public outreach. There is no U.S. experience with the introduction of a LNG passenger vessel or ferry to U.S. waters. LNG terminals have been very controversial, but are different from the introduction of a LNG fueled ferry.

The security planning process and associated public outreach are anticipated to take 18 months at a cost of $1.0 million, which includes $0.7 million for security planning and $0.3 million for public outreach.

Until the security planning review is complete it will also be difficult to know what, if any, additional operation cost may be incurred by WSF or the Washington State Patrol. A full cost-benefit analysis cannot be developed until this information is available.

A. U.S. Coast Guard

The United States Coast (USCG) has the ultimate authority over maritime safety. The local Officer in Charge of Marine Inspection (OCMI) determines the vessels safe operation and is responsible for the issuance of the Certification of Inspection (COI) before the vessel is authorized to sail.

Security is provided by the Washington State Patrol (WSP) and WSF operating under an Alternative Security Plan which has been approved by USCG.

1. LNG Planning Process

The USCG process for LNG terminal approval is outlined in the Navigation and Vessel Inspection Circular (NVIC) No. 01-2011 Guidance Related to Waterfront Liquefied Natural Gas Facilities. It is not clear whether the USCG will require WSF to comply fully with NVIC No. 01-2011 which is designed for review and approval of LNG terminals accepting large deliveries of LNG into U.S. waters.

WSF has said they will seek approval of the USCG to use a modified version of NVIC No. 01-2011. The guidelines allow the Captain of the Port (COTP) to convene an ad-hoc working group of existing security committees - Harbor Safety Committees and Area Maritime Security Committee - and other stakeholders including state and local governments and members of the public to review waterway suitability assessments required of applicants for LNG terminals. WSF will be required to prepare a Waterway Suitability Assessment. Applicants are also encouraged but not required to develop transit management plans.

The primary advantages of this process are:

- *Inter-agency coordination*. The process provides a way to coordinate federal, state, and local public safety and fire reviews across the WSF service area.

- *Encompasses entire WSF service area.* The Puget Sound Harbor Safety Committee encompasses all the WSF routes.
- *Able to incorporate other stakeholders.* The process is designed to encompass other stakeholders include members of the public. There would be an opportunity, for example, to include representatives from the Ferry Advisory Committees.
- *Coordinated by the USCG*. The local COTP would be in charge of the process.

This is anticipated to be a one-time process that would encompass all WSF LNG fueled vessels. WSF's cost estimate for this process is $0.7 million.

Exhibit 2.
LNG Security Planning Cost Estimate
($ in millions)

Security Planning Detail	Cost
WSF Project Manager – 18 months	**$0.1**
Consultant Support	
Labor: Work to be preformed for researching and writing the Waterway Suitability Assessment. The work would be split between two risk assessment specialists.	Estimated Hours:
Port Characterization	80
Characterization of the facilities, vessel routes, and vessels	240
Safety Risk Assessment	160
Security Risk Assessment	240
Threat Assessment	80
Vulnerability Assessment	80
Consequence Analysis	160
Risk Management Strategies	240
Report on Resource Needs for Safety, Security and Response	160
Final report with conclusions	160
Participation In Area Maritime Security Committee & or Harbor Safety Committee	240
Presentation on request	80
Travel Time	160
Total hours for two risk assessment specialists	2,080
Total Cost for Security Consultant	**$0.5**
Non-Labor and ancillary costs	**$0.1**
Total Labor and Non-Labor Cost to research, and facilitate a Waterway Suitability Assessment and produce a product that meets the requirement of Coast Guard Navigation and Vessel Inspection Circular 01-11.	**$0.7**

B. Public Outreach

Public outreach and communication will be an important component of the planned introduction of LNG fueled vessels. It is anticipated that public outreach will occur both during the security planning and as part of the introduction of each LNG vessel to a new route.

1. Public Concerns

There is no U.S. experience with the introduction of a LNG passenger vessel or ferry to U.S. waters. All of the public experience is associated with the approval of LNG terminals and/or trucking LNG to and from such large terminals, which are often very controversial. Public concerns regarding LNG terminal facilities in Oregon and Washington have been one of the most significant reasons that these projects have not moved forward. In the last two years, there has been significant public opposition to re-opening truck capacity at the LNG terminal in Savannah, Georgia and to the construction of a LNG terminal in Maine.

The amount of LNG associated with fueling WSF ferries is much smaller than that associated with a large import terminal. There are also opportunities with WSF ferries for reduced costs and environmental benefits that are not associated with the placement and permitting of LNG terminal facilities.

The issues that have been raised with regards to LNG terminals that could be raised with WSF's use of LNG include the risk of fire and the burden on the community of disaster prevention and relief.

2. Public Outreach Budget

WSF's budget for each LNG vessel project for public outreach is \$0.3 million, which includes communications consultant support (\$0.15 million) and communications staff (\$0.15 million).

C. Implications for LNG Schedule

There is no way to predict the outcome of the security and operation planning review nor is there a way to predict the degree of public support for the conversion. Until the security planning review is complete it will also be difficult to know what, if any, additional operation cost may be incurred by WSF or the Washington State Patrol. A full cost-benefit analysis cannot be developed until this is known.

SECTION V. VESSEL ACQUISTION AND DEPLOYMENT PLAN

This section reviews how the introduction of LNG fueled vessels could affect the vessel acquisition and deployment plan developed as part of WSF's Long-Range Plan.

This section concludes that retrofitting the Issaquah class vessels will have a greater impact on the fleet acquisition and deployment plan than constructing a new 144-car vessel as an LNG vessel. The retrofits cannot begin until the fall of 2014 following the return of the Super class *Hyak* to service from its major renovation. If the Issaquah class retrofits begin before the second new 144-car vessel is in the fleet, WSF plans to retain the *Evergreen State* in service to provide coverage. If not for the retrofit of the Issaquah class vessels, the Evergreen State would retire when the first new 144-car diesel fueled ferry comes on line in 2014.

Once a second new 144-car vessel is in the fleet, WSF can both retrofit the Issaquah class vessels and retire the *Evergreen State.* To avoid disrupting service during the peak summer months, WSF plans to retrofit one Issaquah class vessel per year taking the vessel out-of-service during the fall through early spring. It will therefore take at least six years to complete the full retrofit of the Issaquah class vessels.

Delaying the delivery of the second new 144-car vessel by one year to accommodate its conversion to LNG will delay the planned service improvements and retirement of the *Hiyu* and will require the Evergreen State to stay in service if WSF proceeds with the retrofit of the Issaquah class vessels.

Designing a new 144-car vessel as a LNG fueled vessel could be considered in the context of the next planned procurement of five new 144-car vessels. If funding were available, a new 144-car LNG vessel could be viewed as the first of six such vessels.

A. Current Fleet

WSF has 22 vessels that serve its ten routes in Puget Sound and the San Juan Islands[10]. WSF's Long-Range Plan assumes a 22 vessel fleet through 2030 and establishes a route service plan based on a vessel acquisition and deployment plan.

1. 2012 Fleet

In early 2012, the 63-year old *Rhododendron* will retire from the fleet when it is replaced by the third Kwa-di Tabil (new 64-car) class vessel. WSF will then have three Jumbo Mark II, two Jumbo Mark I, four Super, six Issaquah, three Evergreen State, three Kwa-di Tabil, and one Hiyu class vessels.

One vessel, the *Evergreen State*, is in poor condition and will be retired with the construction of the first new 144-car vessel.[11] The *Hyak* is scheduled for a major renovation and will be out-of-service from September 2013 to July 2014.

The 2012 fleet is shown in Exhibit 3 below.

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[10]From the retirement of the four (4) Steel Electric class vessels in 2007 until the addition of the second Kwa-di Tabil class vessel, the *Salish,* in 2011, WSF operated with a 21 vessel fleet. During this period WSF did not operate a second vessel on the Port Townsend-Coupeville route in the spring, shoulder, summer, and fall seasons as it had done prior to the retirement of the Steel Electrics. With the addition of the Salish second vessel service was restored to the Port Townsend-Coupeville route.

[11] See discussion of Evergreen State*, Joint Transportation Committee Ferry Financing Study II Vessel Preservation and Replacement Final Report*, 2008, p. 5

Exhibit 3.
WSF 2012 Fleet

Class	Vessel	Vehicle Capacity	Year Built / Rebuilt
Evergreen State	*Evergreen State*	87	1954 / 1988
	Klahowya	87	1958 / 1995
	Tillikum	87	1959 / 1994
Super	*Elwha*	144	1967 / 1991
	Hyak	144	1967 / 2014
	Kaleetan	144	1967 / 1999
	Yakima	144	1967 / 2000
Hiyu	*Hiyu*	34	1967
Jumbo Mark I	*Spokane*	188	1972 / 2004
	Walla Walla	188	1973 / 2003
Issaquah	*Issaquah*	124	1979 / ongoing
	Kitsap	124	1980 / ongoing
	Kittitas	124	1980 / ongoing
	Cathlamet	124	1981 / ongoing
	Chelan	124	1981 / ongoing
	Sealth	90	1982 / ongoing
Jumbo Mark II	*Tacoma*	202	1997 / 2027
	Puyallup	202	1998 / 2028
	Wenatchee	202	1998 / 2028
Kwa-di Tabil	*Chetzemoka*	64	2010
	Salish	64	2011
	*Kennewick**	64	2012 (service)

*Replaces the 63-year old *Rhododendron,* which will retire from the feet

2. New 144-Car Vessel Construction

The Legislature's 16-year (2011-2027) financial plan includes the construction of two new 144-car vessels. Funding has been provided in the 2011-13 biennium for the construction of the first vessel with a diesel engine. WSF has awarded the contract for this vessel with delivery in February 2014.

The 16-year plan anticipates a second vessel which may be LNG or diesel. If funding is provided in 2012 and the vessel is constructed as a diesel fueled vessel, delivery could occur in 2015.

As shown in the exhibit below from WSF's Long Range Plan, the first new 144-car vessel will allow the *Evergreen State* to retire. The second new 144-car vessel allows the *Hiyu,* currently the emergency reserve vessel, to retire and a larger Evergreen State class vessel to take its place (the *Hiyu* is in a good state of repair but is too small for reasonable service). The second new 144-car vessel also allows WSF to expand service capacity on the San Juan Islands-Sidney, Fauntleroy-Vashon-Southworth, and Mukilteo-Clinton routes.

3. 2025-2031 Planned Vessel Acquisition

The WSF Long-Range Plan calls for five new-144 car vessels to be built between 2025-2031, which will allow for the retirement of the two remaining Evergreen State class vessels and three Super class vessels, as shown in Exhibit 4 below.

Exhibit 4.
Final Long-Range Plan Fleet Plan

VESSEL ASSIGNMENTS & PROCUREMENT IMPACTS - FINAL LRP PLAN SUMMER

	2009-11	2011-13	2013-2025	2025 - 2031
Anacortes - Sidney (Vessel makes two daily round-trips to Sidney & one to San Juans)	124	124	144 + 20	124
Anacortes - San Juan Islands	144 144 144	144 144 144	144 144 144 New	144 New 144 New 144 New
Interisland	87	87	90	90
Port Townsend - Keystone	64 64 + 64	64 64 + 64	64 64 + 64	64 64 + 64
Mukilteo - Clinton	124 124	124 124	144 New 124 + 20	144 New 144 New + 40
Edmonds - Kingston	202 188	202 188	202 188	202 188
Seattle - Bainbridge	202 202	202 202	202 202	202 202
Seattle - Bremerton	124 188	124 188	124 188	144 New 188 + 20
Fauntleroy - Vashon - Southworth	87 87 124	87 87 124	124 87 124 + 37	124 124 124 + 74
Pt. Defiance - Tahlequah	48	64 + 16	64 + 16	64 + 16
Standby (emergency reserve)	34	34	87 + 53	144 + 110
Maintenance Reserve	144 90	144 90	144 124	144 New 124

KEY

- 202 188 Jumbo Vessel
- 144 Large Vessel
- 124 Medium Vessel
- 90 87 Mid-Size Vessel
- 64 34 Small Vessel
- No Change
- Change in Capacity
- + 16 Change in vehicle capacity

2009-11

- **Two 64-car vessel (Island Home) are delivered**
- **Funding for one 64-car vessels (under construction)**
- Two new 64-car vessels are delivered; one in 2010 & one in 2011 (Port Townsend - Keystone)

2011-13

- **64-car vessel program is complete; delivery of final 64-car vessel**
- **Start new 144-car vessel program**
- One new 64-car vessel is delivered (Pt. Defiance - Tahlequah) in 2012
- Rhododendron is retired

2013-2025

- **Two new 144-car vessels are delivered**
- One new 144-car vessel is delivered in 2014 (Mukilteo - Clinton)
- 124 from Mukilteo - Clinton moves to Fauntleroy - Vashon - Southworth and increases route capacity
- One new 144-car vessel to San Juan Domestic in 2014. 144 from San Juan Domestic moves to Sidney and increases route capacity to both Sidney and San Juan Domestic routes
- 124 from Sidney moves to Fauntleroy - Vashon - Southworth and increases route capacity
- 87 bumped from Fauntleroy - Vashon - Southworth increases standby capacity
- Evergreen State and Hiyu are retired

2025 - 2031

- **Five new 144-car vessels are delivered**
- One new 144-car vessel is delivered in 2027 (Mukilteo - Clinton)
- 124 from Mukilteo - Clinton moves to Fauntleroy - Vashon - Southworth and increases route capacity
- Two new 144-car vessels are delivered in 2028 and 2029 (San Juan Domestic)
- One new 144-car vessel to maintenance in 2028 moves Hyak to standby and retires Klahowya
- One new 144-car vessel is delivered in 2029 to Bremerton.
- 124 from Bremerton moves up to Sidney
- Tillikum and three 144-car vessels are retired (Elwha, Kaleetan, and Yakima)

B. LNG Vessel Construction

WSF has developed construction schedules for the new 144-car vessel as a LNG fueled vessel and for the retrofit of the Issaquah class vessels to LNG. These schedules have been reviewed by the consultants and we concur with the construction timeline.

1. Issaquah Class Vessels

The first vessel will take longer due to design requirements and regulatory review. WSF estimates that the total project time will be 28 months, including:

- *Engine procurement.* Six months to issue a RFP and award an engine contract. Engine delivery takes approximately one year following award.
- *Detail design and regulatory review*. The detail design, which could be undertaken at the same time as the engine procurement RFP, would be complete within a year with phased submittals to the United States Coast Guard's Marine Safety Center for approval. The largest risk factor in this schedule is regulatory review which is discussed in the section on LNG fueled vessel design and construction.
- *Bid*. The bid package would be produced as the drawings are developed. The award of the construction contract could occur 20 months after funding is received.
- *Out-of-service.* The vessel would be out-of-service for 8 months.
    - *Construction.* Construction is anticipated to take six months so the vessel would be complete in 26 months from when funding was available.
    - *Training and sea trials*. Two months following construction.

Subsequent vessels could be built in a shorter time frame because design and regulatory review would be complete. Each vessel being retrofit would be out-of-service for 6 months for construction and one to two months for training and sea trials.

2. New 144-Car Vessel

The new 144-car vessel if constructed as an LNG vessel will require at least an extra year for detailed design and regulatory review than it would for construction as a diesel fueled vessel. If funding were provided in 2013 following security planning, the vessel could be complete in 2017 in contract to 2015 as a diesel fueled vessel.

C. Impact of LNG Fuel Vessel Construction on the Fleet Acquisition and Deployment Plan

Retrofitting the Issaquah class vessels has a greater impact on the fleet acquisition and deployment plan than constructing a new 144-car vessel as an LNG vessel. The retrofits increase out-of-service time of existing vessels, whose service time must be provided from elsewhere in the fleet. If the Issaquah class retrofits begin before the second new 144-car vessel is in the fleet, WSF plans to retain the *Evergreen State* in service to provide coverage. Once a second new 144-car vessel is in the fleet, WSF could both retrofit the Issaquah class vessels and retire the *Evergreen State.*

1. Issaquah Class Retrofit

Retrofitting the Issaquah class vessels cannot begin until after the *Hyak* returns to service and would require that the *Evergreen State* remain in service to provide coverage for the Issaquah class out-of-service periods for retrofits until the second new 144-car vessel is built.

- *Construction of the first retrofit cannot begin until the fall of 2014.* The *Hyak* is anticipated to be out-of-service from September 2013 to July 2014. WSF vessels are fully deployed during the peak summer months, which means as a practical matter that construction of the first Issaquah class vessel retrofit cannot begin until the fall of 2014.[12]
- *Evergreen State.* WSF's Long-Range Plan anticipates retiring the Evergreen State in 2014 when the first new 144-car vessel is delivered. To accommodate the projected 8 month out-of-service time for the first Issaquah class renovation and 7 to 8 month out-of-service of each subsequent vessel, WSF would leave the *Evergreen State* in service until a second new 144-car vessel is delivered.
- *Subsequent Issaquah class retrofits.* To avoid disrupting service during the peak summer months, WSF plans to retrofit one Issaquah class vessel per year taking the vessel out-of-service during the fall through early spring. It will therefore take at least six years to complete the full retrofit of the Issaquah class vessels.

2. Second new 144-car vessel

- *Issaquah class retrofit impact*. The construction of the second new 144-class vessel is a critical path element for the Issaquah class retrofit since until this vessel is available, the Issaquah class retrofits cannot proceed without retention of the *Evergreen State* in the fleet.
- *Delay in service improvements and Hiyu retirement.* Delaying the second new 144-car vessel will delay the service improvements anticipated in the Long-Range Plan and delay the retirement of the *Hiyu*.
- *2025-31 procurement.* Designing a new 144-car vessel as a LNG fueled vessel could be considered in the context of the next planned procurement of five new 144-car vessels. If funding were available, a new 144-car LNG vessel could be viewed as the first of six such vessels.

[12] WSF's initial schedule anticipated the first Issaquah class retrofit to begin in the fall of 2013, which is not possible.

SECTION VI. WSF DIESEL FUEL AND LNG FUEL

This section reviews WSF use of diesel fuel and the potential savings from using LNG fuel.

This section concludes that, based on two LNG price forecasts developed by the consultants, retrofitting all six Issaquah class vessels could save between $139.9 million and $195.5 million in fuel costs over the remaining life of the vessels. For a new 144-car vessel the savings range from $86.3 million to $120.0 million over the life the vessel.

The consultants also considered the potential savings if the three Jumbo Mark IIs could be converted to LNG. The savings range from $355.0 to $494.6 million over the remaining life of these vessels.

Having the LNG fuel contract in place before vessel construction is important both to secure the supply at a known price and to test the motors during construction with the actual fuel to be used. The latter was one of the recommendations from Gasnor and Tide Sjo in Norway.

A. Diesel Fuel

WSF fuels its fleet with ultra low sulfur diesel (ULSD)[13]. RCW 43.19.642 requires state agencies to use a minimum of 20 percent biodiesel blend fuel.[14] In 2011, WSF is using a ULSD that has 5 percent biodiesel with a sulfur maximum content of 0.1 percent.[15]

1. Total Fleet Fuel Consumption

In 2010 WSF used 17.3 million gallons of fuel. Fuel consumption is affected by the size of the vessel, the route the vessel is assigned to, and the speed of the vessel.[16] The five largest vessels in the fleet - the three 202-car Jumbo Mark IIs and the two 188-car Jumbo Mark Is – accounted for 41 percent of total fuel used in 2010. The four relatively fuel inefficient 144-car Super class vessels accounted for another 27 percent of the fuel consumed in 2010 and the six relatively fuel efficient Issaquah class ferries accounted for 22 percent. The remaining six small vessels in service in 2010 accounted for 10 percent of the fuel used.[17]

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[13] Ultra Low Sulfur Diesel is the primary highway diesel fuel produced to meet federal requirements. It can have a sulfur content of no more than 15 parts per million (ppm). ULSD was developed to allow the use of improved pollution control devices that reduce diesel emissions more effectively but can be damaged by sulfur. Most large vessels use bunker fuel, which has sulfur content of approximately 4.5 percent or 45,000 ppm.

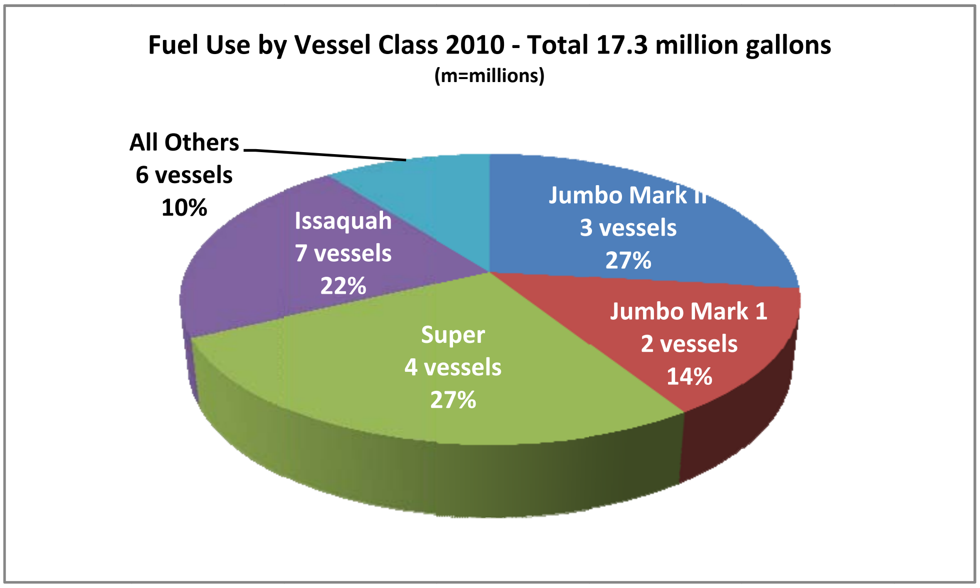
[14] In the 2009-11 biennium WSF was exempted from this requirement and instead required to use 5 percent biodiesel provided that it did not cost more than 5 percent more than diesel fuel. This provision was vetoed by the Governor in the 2011-13 biennium, with the result that WSF is mandated by law to use 20 percent biodiesel. The Legislature had exempted WSF from even the 5 percent biodiesel fuel requirements when it passed the transportation budget. As a consequence the 2011-13 biennium budget assumes no biodiesel fuel even though WSF is required to use fuel with 20 percent biodiesel The Governor has directed WSF to use only as much biodiesel as the fuel appropriation allows.

[15] Product Specification for Ultra Low Sulfur Diesel Fuel #2 Product Code 085 (1).

[16] See the Joint Transportation Committee's *Vessel Sizing and Timing Final Report*, 2009 for further information.

[17] The six vessels are the three Evergreen State class vessels, the Steilacoom II borrowed from Pierce County to operate on the Port Townsend-Coupeville route, the *Chetzemoka* which replaced the Steilacoom II, and the *Hiyu*.

**Exhibit 5.
Fuel Use by Vessel Class 2010**

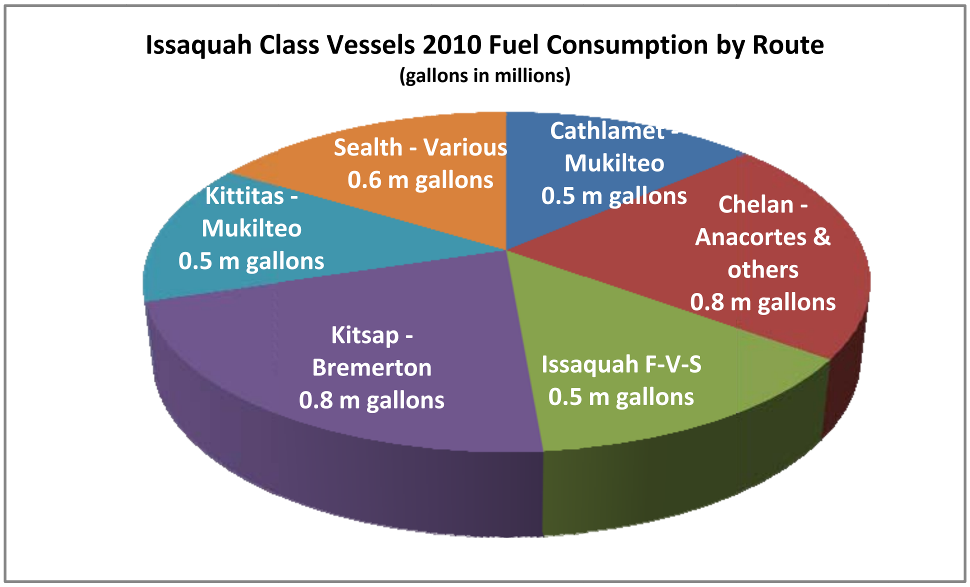


Fuel consumption in FY 2012 is anticipated to increase to 17.5 million gallons with the addition of the *Salish* and the restoration of two vessel service to the Port Townsend-Coupeville route. In FY 2013, fuel consumption will increase to 17.6 million gallons when the *Kennewick* begins service on the Pt. Defiance-Tahlequah route and the *Rhododendron* retires. In 2014, when the first new 144-car vessel is delivered and if the *Evergreen State* retires, annual fuel consumption will increase to 17.9 million gallons. If a second new-144 car diesel vessel is constructed and delivered in 2015, annual fuel consumption will increase to 18.2 million gallons.

2. Issaquah Class Ferries Fuel Consumption

The five 124-car Issaquah class ferries were utilized on four routes in 2010: Mukilteo-Clinton (2 vessels); Fauntleroy-Vashon-Southworth Triangle (1 vessel); Seattle-Bremerton (1 vessel); and Anacortes-Sidney (1 vessel). The 90-car *Sealth* was used as a maintenance reserve vessel on these four routes plus the Pt. Defiance-Tahlequah route. Annual vessel fuel consumption per vessel ranged from 0.5 million to 0.8 million gallons varying with the route and days in service.

**Exhibit 6.
Issaquah Class Vessels 3.7 Million Gallons Fuel Consumption by Route**



Fuel consumption by service hour by route was 77 gallons per service hour for Mukilteo-Clinton; 96 for Fauntleroy-Vashon-Southworth; 145 for Seattle-Bremerton; and 149 for Anacortes-Sidney.

In WSF's Long-Range Plan the Issaquah class vessels are to be re-deployed as the new 144-car ferries come on line. When a second new 144-car vessel is built, two rather than one of the Issaquah class vessels will be assigned to the Fauntleroy-Vashon-Southworth route; one to the Mukilteo-Clinton route rather than two; one (the 90-car Sealth) becomes the Interisland ferry in the San Juans; one remains on the Seattle-Bremerton route; and one is a maintenance reserve vessel.

3. Diesel Fuel Cost

a. Diesel fuel cost projected

Diesel fuel represents 29.2 percent of the 2011-13 biennium operation budget for WSF, or $135.2 million.

The cost delivered to WSF of diesel fuel is adjusted from the Transportation Revenue Forecast Council's forecast by the use of biodiesel, which costs more, and by taxes.

- *Biodiesel*. The adopted budget did not anticipate any use of biodiesel because the Legislature waived the biodiesel requirement for WSF when it adopted the 2011-13 biennium budget. The Governor vetoed that section of ESHB 1175 and directed WSF to use only as much biodiesel fuel as its fuel budget allowed. In practice, WSF is following the 2009-11 biennium requirement to use 5 percent biodiesel provided that it does not cost more than 5 percent more than diesel, even though state law currently requires 20 percent biodiesel fuel.
- *Taxes.* 2ESSB 5742 adopted in the 2011 legislative session eliminates the requirement for WSF to pay sales tax on its diesel or special fuel purchases, effective July 1, 2013.

Using the September 2011 forecast by the Transportation Revenue Forecast Council in the exhibit below, total diesel fuel costs by gallon are $3.77 in FY 2012, dropping to $3.59 in FY 2014 with the elimination of the sales tax, and increasing to $4.03 in FY 2027.

Exhibit 7.
WSF ULSD 16-Year Price Forecast September 2011

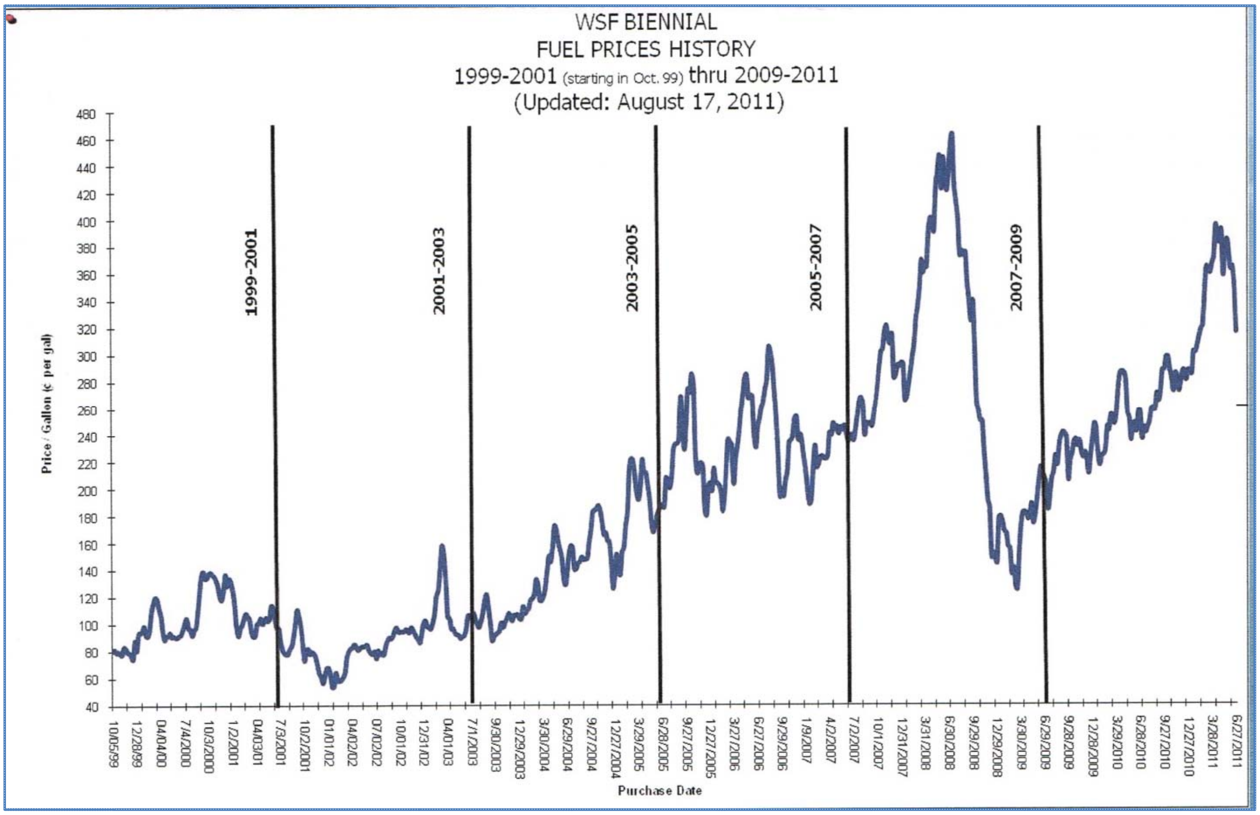
Before taxes and fees:		2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027
Diesel (from September 2011 forecast)		$ 3.28	$ 3.30	$ 3.41	$ 3.39	$ 3.48	$ 3.56	$ 3.61	$ 3.64	$ 3.59	$ 3.57	$ 3.61	$ 3.62	$ 3.65	$ 3.70	$ 3.76	$ 3.82
With 5% biodiesel		$ 3.45	$ 3.47	$ 3.58	$ 3.56	$ 3.66	$ 3.74	$ 3.79	$ 3.82	$ 3.77	$ 3.75	$ 3.79	$ 3.80	$ 3.83	$ 3.89	$ 3.95	$ 4.01
Sales Tax @ 8.9%	8.90%	$ 0.307	$ 0.308	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Federal Oil Spill Recovery Fee	0.19%	$ 0.002	$ 0.002	$ 0.002	$ 0.002	$ 0.002	$ 0.002	$ 0.002	$ 0.002	$ 0.002	$ 0.002	$ 0.002	$ 0.002	$ 0.002	$ 0.002	$ 0.002	$ 0.002
Leaking Underground Storage Ta	0.10%	$ 0.001	$ 0.001	$ 0.001	$ 0.001	$ 0.001	$ 0.001	$ 0.001	$ 0.001	$ 0.001	$ 0.001	$ 0.001	$ 0.001	$ 0.001	$ 0.001	$ 0.001	$ 0.001
Washington State Oil Spill Tax	0.10%	$ 0.001	$ 0.001	$ 0.001	$ 0.001	$ 0.001	$ 0.001	$ 0.001	$ 0.001	$ 0.001	$ 0.001	$ 0.001	$ 0.001	$ 0.001	$ 0.001	$ 0.001	$ 0.001
WA State Hazardous Substance T	0.70%	$ 0.007	$ 0.007	$ 0.007	$ 0.007	$ 0.007	$ 0.007	$ 0.007	$ 0.007	$ 0.007	$ 0.007	$ 0.007	$ 0.007	$ 0.007	$ 0.007	$ 0.007	$ 0.007
Spill Prevention Costs @ $5,200/mon		$ 0.004	$ 0.004	$ 0.003	$ 0.003	$ 0.003	$ 0.003	$ 0.003	$ 0.003	$ 0.003	$ 0.003	$ 0.003	$ 0.003	$ 0.003	$ 0.003	$ 0.003	$ 0.003
Total taxes and fees		$ 0.32	$ 0.32	$ 0.01	$ 0.01	$ 0.01	$ 0.01	$ 0.01	$ 0.01	$ 0.01	$ 0.01	$ 0.01	$ 0.01	$ 0.01	$ 0.01	$ 0.01	$ 0.01
Average Cost per Gallon (including taxes and		$ 3.77	$ 3.79	$ 3.59	$ 3.57	$ 3.67	$ 3.76	$ 3.80	$ 3.83	$ 3.78	$ 3.76	$ 3.81	$ 3.81	$ 3.84	$ 3.90	$ 3.96	$ 4.03

Gallons assumptions
Assumes Kennewick replaces Rhod. In 2012
New 144 in FY 2014 and retirement of E. State
2nd 144 in 2015 diesel

b. Diesel fuel price volatility

As shown in the exhibit below, WSF diesel costs have been quite volatile in the past, with costs per gallon peaking in the 2007-09 biennium.

Exhibit 8.
WSF Diesel Fuel Prices 1999-2011



Source: Washington State Ferries, LNG Fuel Application Seminars, August 31, 2011

Legislative actions to stabilize WSF diesel prices and reduce the impact of spikes in fuel prices on WSF finances are:

- *Fuel hedging program.* For the 2011-13 biennium the Legislature authorized WSF to enter into a distributor controlled fuel hedging program, which it is anticipated will result in lower and more stable WSF diesel prices over time (ESHB 1175, Section 221 (11)). WSF has entered into a hedging contract, and as of October 2011, had hedged approximately 6.2 million gallons of fuel for FY 2012 at an average pre-tax price of \$3.20 per gallon or \$3.67 per gallon with tax and biodiesel.
- *Fuel surcharge.* The Washington State Transportation Commission has adopted a fuel surcharge mechanism effective October 2011 as a way to pay for unexpected spikes in fuel costs. The surcharge mechanism will only be triggered when fuel costs exceed the funded average fuel price by 2.5 percent. WSF will review fuel costs on a quarterly basis and, depending on fuel prices at the time of the review the surcharge may be applied, removed or adjusted higher or lower. The maximum surcharge amount is capped at 10 percent. Any changes to the surcharge requires a 30-day advance notice to customers

B. LNG Fuel

National forecasts by the U.S. Energy Information Administration (USEIA) and other independent analysts project a stable and growing source of domestic supply with relative price stability, largely as the result of the discovery of substantial new supplies of shale gas in the Mountain West, the South and throughout the Northeast's Appalachian Basin.

Prices for natural gas, from which LNG prices are derived, are anticipated to remain relatively low compared to ULSD.

1. Washington State Projections of Natural Gas Supply and Price

Gas utilities operating in Washington State are required to file Integrated Resource Plans (IRP) with the Washington State Transportation and Utilities Commission every two years.[18] Those filed in 2010 and 2011 reflect the national projections for lower natural gas prices. "The projected costs for natural gas have declined significantly and long-term prices are estimated to range between \$5 to \$6 per MMBtu over the planning horizon compared to the \$8 to \$10 forecasted in the 2008 IRP. This improvement to the long-term gas supply outlook is a stark contrast to the diminishing supply outlook that was prevalent during the development of the Company's 2008 IRP" (Cascade Natural Gas 2010 IRP pg. 7).

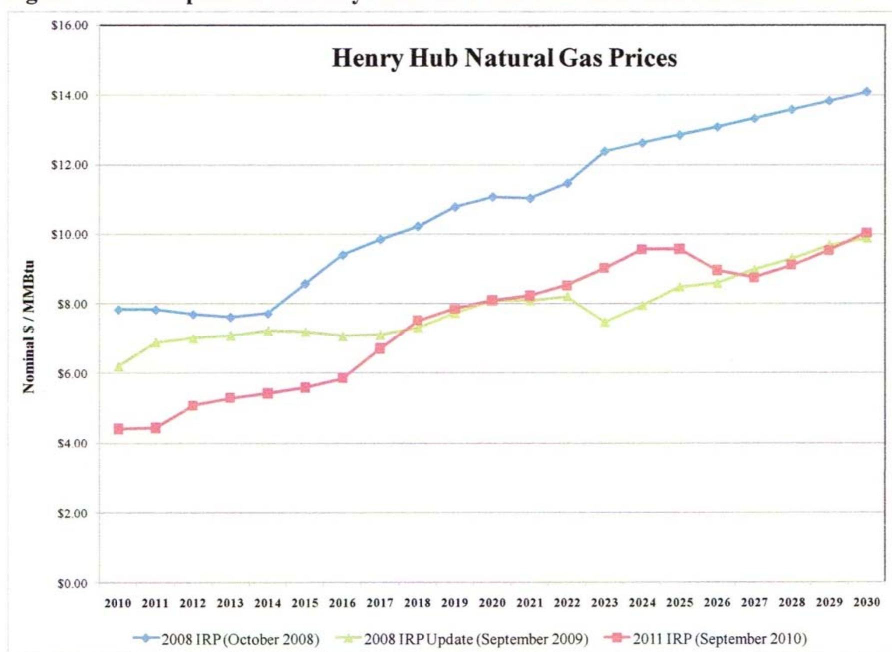
The shift in natural gas prices began in 2007 and 2008 "thanks to an unprecedented and unexpected burst of growth from unconventional domestic supplies across the lower 48 states" (PacifiCorp 2011 IRP, p. 29). Price forecasts by all five utilities are based in part on the Henry Hub gas price forecast. As shown in the exhibit below, the Henry Hub forecast is much lower than it was in 2008.

[18] IRPs are required to be filed by Avista Corporation, Cascade Natural Gas Corporation, NW Natural, PacifiCorp, and Puget Sound Energy.

Exhibit 9.
Comparison of the 2008 Henry Hub Natural Gas Price Forecast through 2035 to a 2011 Forecast

This exhibit shows that the projected price for natural gas through 2035 is lower in the 2011 forecasts than was forecasted in 2008.

Figure 7.6 – Comparison of Henry Hub Gas Price Forecasts used for Recent IRPs

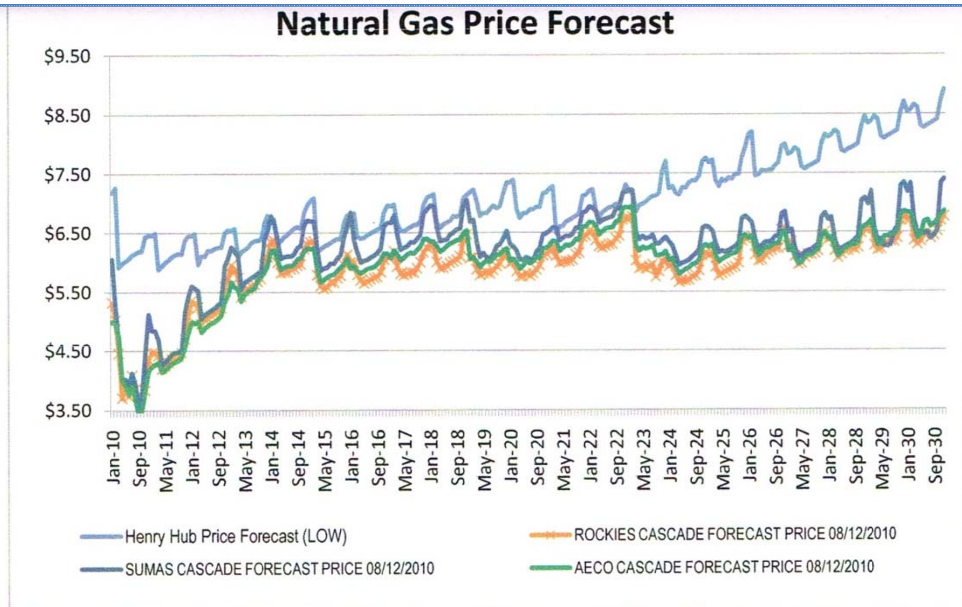


Source: PacifiCorp 2011 Integrated Resource Plan

Natural gas in the Pacific Northwest has been trading at a discount to the Henry Hub prices, which means that the long-term forecast price for natural gas is lower than the Henry Hub natural gas prices. This occurs because the natural gas market in the Pacific Northwest is affected by, among other things, production and imports from Canada. The 2010 forecast by Cascade Natural Gas Corporation shows this differential. The Henry Hub prices are projected to be higher than those from Sumas Cascade, Rockies Cascade, and AECO Cascade hubs where most northwest natural gas is purchased. The forecast also shows that prices are anticipated to remain relatively stable through 2030. Price forecasts by the other natural gas utilities show a similar pattern.

Exhibit 10.
Sample Washington State Natural Gas Price Forecast

This exhibit shows that natural gas prices in Washington State are anticipated to remain relatively stable through 2030 and are lower than the Henry Hub price forecast.

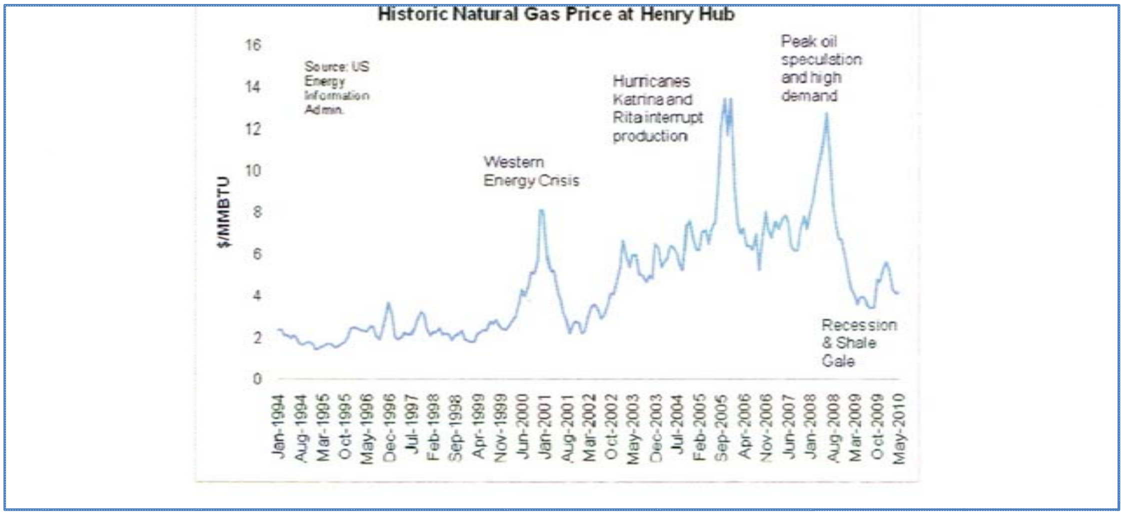


Source: Cascade Natural Gas Corporation 2010 Integrated Resource Plan

2. Volatility in Natural Gas Prices

While natural gas prices are more stable than diesel prices, they also experience volatility. As shown in the exhibit below, natural gas prices spiked in 2000-2001 with the energy crisis, in 2005 from the impact of hurricanes Katrina and Rita, and in 2008 with oil speculation and high demand.

Exhibit 11.
Volatility in Natural Gas Prices 1994-2010



Source: NW Natural 2011 Integrated Resource Plan

The IRPs point to further price uncertainty in the mid- to long-term including the potential for prices to increase due to difficulties in extracting shale oil, potential drilling restrictions due to environmental concerns, and the potential of a "concerted U.S. policy effort to shift the transportation sector away from oil toward natural gas which would significantly increase demand, and thus natural gas prices" (PacifiCorp IRP 2011, pg. 29). Other factors that affect natural gas prices include oil price volatility, the global economy, electric generation, hurricanes and other weather conditions, and the potential environmental moves to shift from coal-generated electricity to natural gas.[19]

3. Liquid Natural Gas Supply

There are three types of LNG facilities that are involved in the supply of LNG: LNG terminals which handle import and export of LNG; liquefaction facilities where natural gas is converted to LNG; and storage facilities where LNG is stored for future use.

LNG facilities are primarily in the eastern United States and on the Gulf Coast. There are relatively few in the western United States and very few in the Pacific Northwest.

a. LNG import terminals

There are eleven U.S. LNG import terminals in the Gulf and East Coasts, some of which are also authorized to export LNG. Each of the import facilities, with the exception of Gulf Gateway, has a regasification facility or capability to support the distribution of gas by pipeline.[20] In addition to the U.S. import terminals, there is one terminal in Canada and two terminals in Mexico that supply the U.S. natural gas market.

[19] Centralia's Big Hanaford power plant is a major coal-fired power plant supplemented with newer natural-gas-fired units. It is the only commercial coal-fired power plant in Washington State. During the 2011 legislative session an agreement was made that will result in both coal boilers being shut down by 2025.
[20] One facility, the Gulf Gateway, handles a specialized LNG carrier that does the regasification on board.

The Federal Energy Regulatory Commission (FERC) has the primary authority for the approval of import and export LNG terminals under the federal Natural Gas Act. But that authorization is conditioned on the applicant's satisfaction of other statutory requirements for various aspects of the project. Substantial authority exists through current federal statutes pertaining to those aspects of the project for states to authorize or block and thereby effectively veto development of an LNG facility. State permits must be issued under the Clean Air Act (Section 502), Clean Water Act (Section 401), and the Coastal Zone Management Act (Section 307A). In addition states may be a cooperating agency with FERC during the review of a project under the National Environmental Policy Act (NEPA), and can contribute to the complete environmental review of the proposal. [21]

There are two additional LNG import terminals that have met all approval processes and are under construction: one in Elba Island, Georgia, which is expanding its current location, and one in Pascagoula, Mississippi.

There are 11 import terminals that have been approved by FERC but are not under construction for a variety of reasons, including permitting difficulties, local opposition, and/or changes in market conditions that are projected to limit LNG imports with the discovery of U.S. shale gas reserves.

The closest import facility to Washington State that has FERC approval is in Coos Bay, Oregon – the Jordan Cove LNG Terminal Project.[22] The terminal would include two LNG storage tanks each with a capacity of 1 million barrels, a turbine power plant, and a single LNG carrier unloading berth. The project would connect to the Pacific Connector Gas Pipeline. A notice of intent was submitted to FERC for this project in November 2004 and the project is still in the permitting process with the State of Oregon. In June 2011, the Western Environmental Law Center asked FERC to conduct a new analysis of the LNG project, saying the developers were considering exports. In August 2011 the developers indicated that they make seek FERC approval for a dual-use import/export facility.[23] The project is controversial, with significant environmental opposition. None of the IRPs include gas from Jordon Cove in their base forecast.

b. Liquefaction and storage facilities

There are approximately 100 liquefaction and storage facilities in the United States, with most of them located in the east. Relatively few facilities are located in the west and most of those are peak-shaving facilities, which are facilities that store surplus natural gas for utilities that is to be used to meet the requirements of peak consumption later during winter or summer. Each peak-shaving facility has a regasification unit attached, but may or may not have a liquefaction unit. Facilities without a liquefaction unit depend upon tank trucks to bring LNG from other nearby sources to them.

There are very few liquefaction and/or storage facilities in the Pacific Northwest and those that exist are supporting the gas utilities.

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[21] http://www.ferc.gov/industries/gas/indus-act/lng/state-rights.asp

[22] There are three other possible LNG facilities in Oregon but none of them have FERC approval at this point and all three are facing substantial financing and other problems. These include the Port Westward LNG facility, the Northern Star LNG facility at Bradwood, and the Oregon LNG facility at Astoria. An export LNG facility is proposed for Kitimat British Columbia. That project has received environmental approvals and should come on line in 2013. See *West Coast LNG Projects and Proposals* California Energy Commission June 2011 for more information.

[23] http://www.firstenercastfinancial.com/news/story/44336-williams-official-strong-interest-lng-exports-jordan-cove

- *Plymouth LNG.* NWP (Williams-Northwest Pipeline) owns and operates a liquefaction, storage, and regasification facility at Plymouth Washington. Gas from Plymouth is currently fully contracted and used primarily to meet needle peak demand, which means that it is used during periods of extremely high demand over a relatively short time (i.e. 10 days or less). Plymouth is not currently authorized by FERC to sell to customers other than utilities.
- *Gig Harbor LNG.* Puget Sound Energy owns and operates a satellite LNG facility that services its Gig Harbor area market. The plant receives, stores, and vaporizes LNG that is liquefied elsewhere.
- *Newport LNG facility.* NW Natural owns and operates a liquefaction and LNG storage facility in Newport, Oregon, which supplies the Gig Harbor LNG storage facility. NW Natural is considering the addition of a compressor that would increase output at the plant.
- *GASCO LNG facility.* NW Natural also owns and operates a LNG liquefaction and storage facility in Portland, Oregon.
- *Nampa LNG facility.* Intermountain Gas Company owns and operates a LNG facility in Nampa, Idaho.
- *British Columbia.* FortisBC owns and operates two LNG production and storage facilities, one at Tilbury on Vancouver Island and one at Mt. Hayes. This is the supplier that BC Ferries is working with. FortisBC is in the process of expanding production capacity. In consultant interviews, FortisBC representatives have indicated that they anticipate having sufficient supply to meet WSF's initial LNG requirements.

Terasen Gas is constructing an additional LNG peak shaving facility in Vancouver, Washington, which is scheduled to open this year. There is discussion among utilities serving Washington State of participating in a regional LNG storage facility to provide additional needed peak capacity and some are considering additional satellite LNG storage facilities.

Permitting for U.S. liquefaction and storage facilities is subject to FERC requirements if the natural gas is intended for use in interstate commerce. There are constraints on the use of such gas. Section 4 of the Natural Gas Act (15 U.S.C. 717c) was amended in 2005 to allow FERC to grant authority to natural gas companies to "provide storage and storage-related services at market-based rates for new storage capacity related to a specific facility placed in service after the date of enactment of the Energy Policy Act of 2005, notwithstanding the fact that the company is unable to demonstrate that the company lacks market power, if the Commission determines that: 1) market-based rates are in the public interest and necessary to encourage the construction of the storage capacity in the area needing storage services; and 2) customers are adequately protected (Section 4f)."

4. Liquid Natural Gas Supply for WSF

In interviews with potential suppliers and with others, three options have been identified to supply LNG for WSF needs.

- *Participate in the construction and/or operation of a LNG liquefaction and storage facility.* Some of those interviewed have suggested that WSF could consider participating in the construction and operation of liquefaction and storage facility to meet its needs.
- *Truck LNG from outside the Pacific Northwest.* Another option is to contract for LNG from a broker or supplier who would supply LNG by trucking it from out-of-state. This source would be available today.

- *Truck LNG from within the Pacific Northwest.* Discussions with FortisBC indicate that they could be a potential supplier for WSF. There are also other entities considering expanding capacity in the Pacific Northwest.

The consultants' analysis is based on the assumption that, in the worst case, WSF would have to truck LNG in from outside the Pacific Northwest or, in a better case, LNG could be trucked from FortisBC or another Pacific Northwest supplier. Constructing a liquefaction facility is not a viable option in the short term consideration of LNG fueled vessels because of the costs, schedule implications, and permitting difficulties.[24]

5. Liquid Natural Gas Price Forecasts for WSF

The consultants have developed two price forecasts for WSF LNG: the first assumes trucking LNG from outside the Pacific Northwest and the second assumes a Pacific Northwest supplier. If LNG can be obtained from a facility in the Pacific Northwest it will lower the cost of transportation and provide less supply chain risk than a more distant alternative.

a. Trucking from outside Pacific Northwest forecast

The consultants worked with the Transportation Revenue Forecast Council that provides the ULSD price forecast to develop a LNG price forecast. The consultants used the Henry Hub long-term natural gas forecast provided by WSDOT and then worked with Poten & Partners, an energy consulting firm, to develop the base price per gallon, and additional cost factors for liquefaction and transport. Poten & Partners provided a cost estimate of 30 cents a gallon for trucking LNG from Boron, California and assumed a 15 percent return on investment for liquefaction. The consultants used the Henry Hub forecast to estimate the cost of gas going forward and then inflated the cost of liquefaction at 1.5 percent annually, a figure recommended by Poten & Partners, and used the WSDOT diesel fuel retail forecast as a basis for inflating the cost of trucking transportation. Poten & Partners cautioned that the initial delivery cost would be up to six cents a gallon higher per gallon due to the small initial demand as the LNG ferries come on line. They also believe LNG suppliers are likely to try and peg their price to the alternative source available, in this case, ultra low sulfur diesel.

In comparing LNG costs to ULSD the energy basis of the costs are compared. LNG has approximately 58 percent of the BTU content of an equivalent volume of ULSD, meaning that it takes more LNG to produce the same amount of energy as ULSD produces. The consultants multiplied the price of one gallon of LNG by 1.7 to create an equivalent cost per gallon of LNG.

As shown in Exhibit 12, the forecast shows that WSF could save 40 percent per gallon on fuel in 2015 narrowing to 36 percent by 2027. The annual savings will depend on which vessels on which routes use LNG fuel.

[24] Interviews have suggested that a small liquefaction facility could be cost approximately $15 million. However, without knowing the site or potential partners it is difficult to estimate the exact cost.

Exhibit 12.
LNG 16-Year Price Forecast Outside the Pacific NW Delivered for WSF Use

Year	2015	2020	2025	2027
WSF ULSD Sept. 2011 Forecast	**$3.57**	**$3.78**	**$3.90**	**$4.03**
Henry Hub Natural Gas Price per 1 million MMBTU	$5.04	$5.49	$6.09	$6.45
Conversion Factors for Henry Hub Natural Gas Commodity to LNG Price				
Gas Gallon	$0.50	$0.55	$0.61	$0.64
Liquefaction	$0.44	$0.47	$0.51	$0.53
Trucking	$0.31	$0.33	$0.34	$0.35
Price per LNG Gallon	**$1.25**	**$1.35**	**$1.46**	**$1.52**
ULSD Equivalent Price with 1.7 G LNG=1 G ULSD Adjustment	**$2.13**	**$2.30**	**$2.48**	**$2.58**
Savings Per Gallon	**$1.44**	**$1.48**	**$1.42**	**$1.44**
Percent Savings	**40%**	**39%**	**36%**	**36%**

b. Forecast for Delivery from Pacific Northwest Supplier

The consultants used pricing information provided by FortisBC, a Canadian supplier of peak shaving natural gas to utilities that is expanding production and delivery capabilities, to develop this forecast. FortisBC sells at regulated tariffs and provided information on their price per gallon of gas purchased with the Sumas Natural Gas Index. The consultants then inflated this going forward at the same rate as the Henry Hub Forecast. The Sumas Index is lower than the Henry Hub but the rate of increase is expected to be the same for both going forward. FortisBC provided their liquefaction and production rates and use the CPI as an inflation factor. Trucking was estimated at a ten-hour roundtrip at $100 an hour today, with the same inflation factor as was used for liquefaction and production applied. FortisBC believes they will have sufficient capability to meet WSF's initial demands and will have room to expand as regional demand grows in the future.

Exhibit 13.
LNG 16-Year Price Forecast Pacific NW Supplier Delivered for WSF Use

Year	2015	2020	2025	2027
WSF ULSD Sept. 2011 Forecast	**$3.57**	**$3.78**	**$3.90**	**$4.03**
Sumas Natural Gas Price Index Per Gigajoule	$4.50	$4.91	$5.44	$5.77
Conversion Factors for Sumas Natural Gas Commodity to LNG Price				
Gas Gallon	$0.39	$0.42	$0.47	$0.50
Liquefaction	$0.38	$0.44	$0.51	$0.54
Trucking	$0.11	$0.13	$0.15	$0.15
Price per LNG Gallon	**$0.87**	**$0.99**	**$1.12**	**$1.19**
ULSD Equivalent Price with 1.7 G LNG=1 G ULSD Adjustment	**$1.41**	**$1.59**	**$1.81**	**$1.92**
Savings Per Gallon	**$2.16**	**$2.19**	**$2.09**	**$2.11**
Percent Savings	**60%**	**58%**	**54%**	**52%**

Based on discussions with Canadian supplier assuming exchange rate 1 USD = 1.021 CD

c. Liquid Natural Gas Price Forecasting for Other Agencies

The consultants discussed LNG price history and forecasting with Phoenix Public Transit, who have been using LNG in their bus fleet for a number of years; and BC Ferries, who are undertaking a feasibility study for the conversion of a diesel ferry to LNG.

Phoenix Transit uses 11.5 million gallons of LNG annually, which is approximately twice the amount WSF would use in a year if all six Issaquah class ferries were converted to LNG. Phoenix does not forecast LNG prices other than for short term budgeting. In the near term for budgeting they assume a 5 percent per year increase.

The price per gallon they have paid for LNG delivered, excluding taxes, is shown in the exhibit below. Phoenix is paying $1.05 per gallon before tax in 2011 and is at the end of a three year contract with Clean Energy.

As shown in the exhibit below, Phoenix has experienced considerable volatility in LNG fuel costs, with costs peaking in 2008.

Exhibit 14.
Phoenix Transit LNG Cost per Gallon FY 2004-2011

Fiscal Year	2004	2005	2006	2007	2008	2009	2010	2011
Price	$0.63	$0.68	$0.69	$0.70	$1.60	$0.87	$0.99	$1.05
Increase		**8%**	**1%**	**1%**	**129%**	**-46%**	**14%**	**6%**

BC Ferries solicited input from three forecasting firms and found that all three came back showing stable prices going forward, with a small narrowing of the price gap between natural gas and diesel. They have discussed a price including taxes and delivery with their potential local supplier and currently forecast a 60 percent savings with LNG based on July, 2011 natural gas spot and diesel prices.

6. LNG Fuel Cost Saving Scenarios

a. Issaquah class fuel savings

WSF's vessel acquisition and deployment plan assumes that each vessel will have a 60-year life. The remaining life of the Issaquah class vessels at the point they are retrofit is a limiting factor in how much savings can be realized.

If the Issaquah class vessels are renovated on the fastest possible schedule, with the first retrofitted vessel in service in 2015 and then one vessel done each subsequent year, the remaining life of the Issaquah vessels at the point of their retrofit would be 23 to 25 years as shown in the exhibit below.

Exhibit 15.
Issaquah Class Vessel Life Remaining Following LNG Retrofit (Most Aggressive Schedule)

Vessel	Year Built	Year LNG Conversion	Remaining Life (years)
Issaquah	1979	2015	24
Kitsap	1980	2016	24
Kittitas	1980	2017	23
Cathlamet	1981	2018	24
Chelan	1981	2019	23
Sealth	1982	2020	22

With this retrofit plan, the fuel savings for the Issaquah class boats from the first 2015 conversion to the retirement of the last vessel in 2042 are $139.9 million based on outside the Pacific Northwest delivery price forecast or $195.5 million with Pacific Northwest delivery. By comparison, the diesel cost for the period is $381.4 million.

Exhibit 16.
Issaquah Class Six Vessel Fuel Savings Range 2015-2042

(YOE dollars in millions)

Forecast	2015	2020	2025	2030	2035	2040	2042	Total Savings
Out-of PNW Delivery Forecast	-$0.8	-$5.5	-$5.3	-$5.7	-$6.2	-$5.8	-$1.1	-$139.9
PNW Delivery Forecast	-$1.1	-$7.8	-$7.4	-$7.9	-$8.6	-$8.0	-$1.6	-$195.5

Fuel costs savings after the 2027 diesel fuel forecast are based on the assumption that the difference between LNG and diesel remains constant from 2027 forward. This is consistent with national projections through 2035 that the differences will remain constant.

The Issaquah class cost savings would be reduced if the vessels are renovated at a later date.

b. New 144-car Vessel

Projected savings for the new 144-car vessel assuming service on the Anacortes-San Juans route beginning in 2016 over the 60-year life the vessel are $86.3 million based on outside the Pacific Northwest delivery price forecast or $120.0 million with Pacific Northwest delivery. Diesel costs are estimated to be $238.6 million.

Exhibit 17.
New 144-Car Vessel Fuel Savings Range 60 Year Life (Begin 2016)

(YOE dollars in millions)

Forecast	2016	2026	2036	2046	2056	2066	2076	Total Savings
Out-of PNW Delivery Forecast	-$1.0	-$1.0	-$1.1	-$1.3	-$1.6	-$1.9	-$2.3	-$86.3
PNW Delivery Forecast	-$1.4	-$1.3	-$1.5	-$1.8	-$2.2	-$2.6	-$3.1	-$120.0

Fuel costs savings after the 2027 diesel fuel forecast are based on the assumption that the difference between LNG and diesel remains constant from 2027 forward. This is consistent with national projections through 2035 that the differences will remain constant.

c. Other Vessel Retrofits – Jumbo Mark IIs

The only other vessels that WSF could consider retrofitting for LNG fuel are the Jumbo Mark IIs. The Jumbo Mark 1 and Super class vessels are too old to justify a retrofit and the other smaller vessels consume too little diesel fuel to make a retrofit an economic investment.

Although retrofitting the Jumbo Mark IIs would be a more difficult project, the fuel cost savings could be very significant.

The three Jumbo Mark IIs consume 27 percent of WSF's fuel and would have, as of 2015, 41-42 years of remaining life.

Exhibit 18.
Jumbo Mark II Class Vessel Life Remaining Following Potential LNG Retrofit (Most Aggressive Schedule)

Vessel	Year Built	Year LNG Conversion	Remaining Life (years)
Tacoma	1997	2015	42
Puyallup	1998	2016	42
Wenatchee	1998	2017	41

With this retrofit plan, the fuel savings for the Jumbo Mark II class boats from the first 2015 conversion to the retirement of the last vessel in 2058 are $355.0 million based on outside the Pacific Northwest delivery price forecast or $494.6 million with the Pacific Northwest delivery forecast. Current estimated diesel costs are $975.7 million.

Exhibit 19.
Jumbo Mark II Class Three Vessel Fuel Savings Range 2015-2058

(YOE dollars in millions)

Forecast	2015	2025	2035	2045	2050	2058	Total
Out-of PNW Delivery Forecast	-$2.2	-$6.6	-$7.7	-$9.2	-$10.0	-$7.7	-$355.0
PNW Delivery Forecast	-$3.2	-$9.2	-$10.7	-$12.7	-$13.9	-$10.6	-$494.6

Fuel costs savings after the 2027 diesel fuel forecast are based on the assumption that the difference between LNG and diesel remains constant from 2027 forward. This is consistent with national projections through 2035 that the differences will remain constant.

7. Fuel and LNG Schedule

Having the LNG fuel contract in place before vessel construction is important both to secure the supply at a known price, and to test the motors during construction with the actual fuel to be used. The latter was one of the recommendations from Gasnor and Tide Sjo in Norway.

SECTION VII. LNG VESSEL BUNKERING AND MAINTENANCE

This section reviews LNG bunkering and maintenance costs. This section concludes that bunkering for LNG is a more complex operation than diesel fueling and may require operational adjustments. Maintenance costs are anticipated to be the same as for diesel fueled vessels, although the USCG could change required staffing when it issues the Certificate of Inspection. WSF should retain the services of a classification society to inspect and monitor the LNG vessels during the first at least ten years of operation.

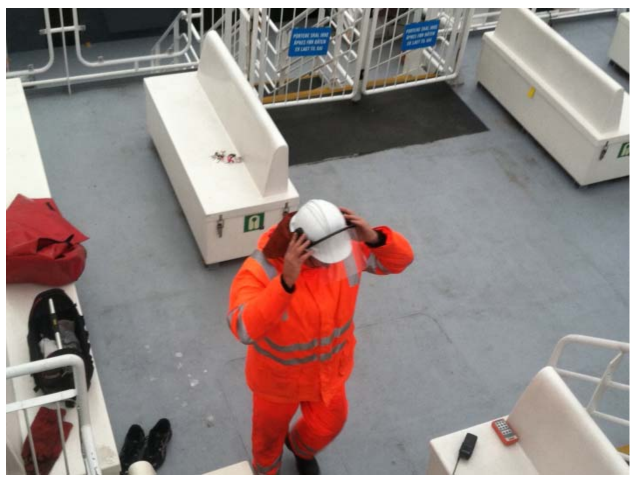
A. Bunkering

Refueling or bunkering of LNG is a more complex operation than diesel fueling and may require operational adjustments.

On the routes with planned service by an Issaquah class or new 144-car vessel, WSF currently fuels by truck at the Bremerton terminal for the Seattle-Bremerton route, Southworth terminal for the Fauntleroy-Vashon-Southworth route, the Clinton terminal for the Mukilteo-Clinton route, and the Anacortes terminal for all the San Juans routes.

1. LNG Bunkering

The consultants observed the fueling of vessels in Norway. In Oslo for the Tide Sjo passenger only ferries fueling takes place by truck, the same as the WSF LNG vessels would under current plans.



Fueling takes place with an adjustable hose that is attached to the fueling truck. The line is cleared with nitrogen before and after the fuelings on each vessel to ensure that LNG does not leak into the atmosphere. As shown in the photo to the right, the driver and both deckhands monitoring the fueling, who are stationed at the above deck bunkering station, all wear fire protection suits with face shield. The Chief Engineer monitors the process from the deck and the fueling can be halted by any of the three, who are in radio contact, if necessary.

Upon completion of the fueling, the driver, the crew at the bunkering station and the Chief Engineer go through an extensive safety checklist as the nitrogen is venting the line and the hose is disconnected.

2. Diesel Fueling

The consultants also viewed a fueling by truck of one of the existing Issaquah class vessels on the Seattle-Bremerton route. Two trucks drove onto the ferry on the Seattle side and fueling took place at the end of the last sailing of the day at Bremerton. The Chief Engineer and engine room crew go through a short safety meeting before fueling to ensure the vessel is ready for fueling and all their communication equipment is working in case of emergency

They then lay out boom and devices on deck to stop any diesel fuel leaks from going overboard. The driver verifies the amount to be delivered, in this case 16,900 gallons, and the engine room staff plots how they will split the load between the fuel tanks to ensure proper ballast. During fueling the two truck drivers feed the diesel fuel by gravity to the vessel fuel tank. They were overseen by the Assistant Chief Engineer on the deck, while the oiler measured the height of fuel in the tanks as they fueled with a sounding tape. No hazardous material gear is required other than gloves. The process is less automated than LNG fueling, which requires the pressure to be constantly monitored and the fill level of the tanks is measured by computer.

Oiler (blue glove) Measuring diesel fuel tank level aboard WSF with measuring stick (left) and measurement system for LNG on Fjord1 vessel (right) that monitors whole system for pressure and potential leaks


Issaquah class fueling station *LNG bunkering station – Tide Sjo*

B. Classification

Classification of operating vessels involves inspections by the classification society to determine if the vessel operation and status are in compliance with applicable rules. WSF does not maintain class on its diesel vessels nor do the Norwegian ferry operators the consultants interviewed. The Norwegian ferry operators have maintained class on their LNG fueled vessels because of the relative sophistication of the vessels and limited experience with operating them. The classification society Det Norske Veritas (DNV) has provided an estimated cost of $15,000 per vessel per year for on-going classification services.

C. Maintenance Costs

Projections for maintenance cost of a new 144-car diesel vessel are based on the maintenance costs for the Issaquah class vessels. Annual maintenance costs, excluding engine room labor, for each Issaquah class vessel and the new 144-car diesel vessel are approximately $0.7 million: $0.3 million for engine room non-labor supplies; $0.3 million for shipyard and other contract maintenance; and $0.1 for Eagle Harbor work.

1. Motor Repair/Overhaul

Fjord1 reported in 2010 that their costs for routine LNG vessel motor maintenance for the *Glutra,* their first LNG fueled passenger vessel, had been 20 percent higher than for a similar-sized diesel vessel. Fjord1 also report that maintenance costs of its five sister ships in operation since 2007 have been 10 percent higher. Consultant interviews with Fjord1 in October 2011 and interviews with Tide Sjo in Oslo indicate that maintenance costs for the LNG vessels are now projected to be the same as for their diesel vessels.

Cost estimates developed by The Glosten Associates for the new 144-car diesel vessel and the LNG fueled vessel show similar motor maintenance and repair costs for both versions of the vessel at $0.1 million per year in 2011 dollars assuming a center section overhaul every 30,000 hours, an intermediate overhaul every 60,000 hours, and a major overhaul every 120,000 hours for both types of engines.

The Norwegians are finding that oil changes can be possibly extended to 30,000 service hours from the normal 8,000 service hours because the engine is so clean.

D. Engine Room and Deck Staffing

The Issaquah class ferries operate with three staff in the engine room 24-hours a day and 11 deck staff when the vessel is in service. The 90-car Sealth has a deck staff of 10 rather than 11. The 16-year financial plan assumes that the new 144-car vessel will have the same staff requirements as the Issaquah class.

The USCG makes the determination on minimum staffing levels. This analysis assumes that there are no changes in staffing requirements with LNG fueled vessels.

SECTION VIII. VESSEL DESIGN AND CONSTRUCTION

This section reviews the regulatory requirements that will govern WSF LNG vessel design and construction and includes a discussion of important design and construction considerations. This section concludes that:

- The USCG design and construction regulatory process, which is in addition to the safety planning, will take longer than normal because there are no approved USCG rules. In the absence of specific rules, the USCG can review and approve alternative designs under 46 CFR 50.20-30.Using its authority under 46 CFR 50.20-30, the USCG responded to WSF's 144-car vessel *Regulatory Review of Concept* with a letter that will be the basis for the USCG design review. A request for *Regulatory Review of Concept* was submitted to the USCG for the Issaquah class retrofit in September 2011.
- The USCG could decide that the Issaquah class vessels are a major conversion, which would require WSF to bring these 30-year old vessels up to current standards. This would be cost prohibitive. It will be important for WSF to have a major conversion determination from the USCG before proceeding with the construction of an Issaquah class retrofit.
- Given the complexity of LNG systems, WSF should consider contracting for design with a firm (or firms) that have experience in LNG fueled systems and should consider requiring the shipyard to retain an expert with LNG construction experience.

A. Design Regulatory Requirements

There are regulatory differences between diesel and LNG fueled ferries. The USCG has not developed rules governing the design of LNG fueled passenger vessels. This introduces an element of regulatory uncertainty that is not present when designing and building a diesel fueled vessel.

WSF's conceptual design work for the re-design of the new 144-car ferry, much of which has been done by their contracted naval architect The Glosten Associates, is the most advanced design work that has been done in the United States on a LNG fueled passenger vessel. If the new 144-car ferry is built as an LNG fueled vessel or an Issaquah retrofit is undertaken, it will most likely be the first LNG fueled passenger vessel subject to U.S. regulations.

1. International Maritime Organization (IMO)

IMO is the United Nations specialized agency with responsibility for the safety and security of shipping and the prevention of marine pollution by ships. IMO, through working groups comprised of all interested countries, produces International Codes governing the carriage of all manner of cargoes. IMO Resolution (MSC.5 (48) covers the construction and equipment of ships carrying liquefied gases in bulk. One of those liquefied gases is LNG.

IMO has passed Resolution MSC.285(86) (reference (b)), "Interim Guidelines on Safety for Natural Gas-Fueled Engine Installations in Ships", but it is a guideline, and not considered an international convention as it has not been vetted; as such, it is at the discretion of the flag state as to whether to accept these rules.

The IGC code, the rules on how gas carriers can store, handle and use gas as a fuel, is being revised at the same time that a set of interim guidelines on the use of LNG as a fuel, known as the IGF code, in other vessels is being developed and solidified. The deadline for confirming the IGF code has been extended to 2014 from an original goal of 2012 in part to resolve contradictions between the two codes. This has increased the uncertainty about the direction of IMO rules.

2. Det Norske Veritas (DNV)

DNV is a Norwegian classification society organized as a foundation, with the objective of "safeguarding life, property, and the environment." DNV describes itself as a provider of services for managing risk. Together with Lloyd's Register and American Bureau of Shipping, DNV is one of the three major companies in the classification society business.

DNV has classed (i.e. developed applicable rule requirements and certified that the vessels conform to those requirements) all existing LNG fueled vessels, including ferries, and therefore has the most experience and the best established rules concerning LNG fueled vessels. In their rules, Part 6, chapter 3 of "Gas Fueled Engine Installations", under paragraph A100 on page 107, entitled "Application", Guidance note 1, they note that the use of gas as a fuel in ships, other than LNG tanker ships, is not presently covered by international conventions and thus such installations will need additional acceptance by the flag state.

3. United States Coast Guard (USCG)

The USCG does not have rules for LNG fueled passenger vessels, but has agreed to recognize IMO Resolution MSC.285(86), "Interim Guidelines on Safety for Natural Gas-Fueled Engine Installations in Ships" until such time as USCG guidelines are adopted. The USCG has provided to WSF/Glosten significant additional guidance which is discussed below.

Design and vessel plan approval is a separate and distinct process from the safety planning process discussed above. This regulatory review will be required in addition to the safety planning process.

a) Design and Plan Approval

In the absence of specific rules, the USCG can review and approve alternative designs under 46 CFR 50.20-30 - Alternative materials or methods of construction which states:

> (a) When new or alternative procedures, designs, or methods of construction are submitted for approval and for which no regulations have been provided, the Commandant will act regarding the approval or disapproval thereof.
>
> (b) If, in the development of industrial arts, improved materials or methods of construction are developed, their use in lieu of those specified will be given consideration upon formal application to the Commandant, with full information as to their characteristics, together with such scientific data and evidence as may be necessary to establish the suitability of such materials or methods of construction for the purpose intended.

Because the USCG has not yet adopted rules in the Code of Federal Regulations (CFR) addressing the design of LNG fueled passenger vessels and must instead rely on 46 CFR 50.20-30, American ship builders and designers have an uncertain regulatory environment within which to design and construct LNG fueled passenger ferries.

In using its authority under 46 CFR 50.20-30 to review LNG fueled passenger vessels, the USCG is relying on IMO and, to some extent, DNV rules.

With CFR and classification rules in place the process, such as with a diesel fueled passenger vessel, involves designing the vessel to those rules and submitting the developed design to the USCG and classification society for approval. In these circumstances the USCG will not start review of a design until there is a letter of intent or contract with a shipyard as they have limited resources to carry out plan approval. In recent years, to reduce the plan approval and inspection load on the USCG, the Alternate Compliance Program has been developed where the classification society takes over most of the USCG design approval and shipyard inspection role. Depending on the type of vessel, the USCG might still reserve approval and inspection rights for certain systems.

For LNG fueled passenger vessels, the lack of specific regulations will mean that the USCG will play a larger role in plan approval. WSF/Glosten submitted a *Regulatory Review of Concept* for the new 144-car vessel which contains a general narrative of the intended design. The review concludes with conclusions and critical review items to show the USCG where the greatest uncertainties lie and, most importantly, the review contains appendices that tabularize DNV and IMO rules with comments as to how the design meets, or does not meet, those rules.

The USCG responded to the 144-car vessel *Regulatory Review of Concept* with a letter that will be the basis for the USCG design review of the new 144-car LNG fueled ferry. This letter states: "The Marine Safety Center (MSC) will use this regulatory design basis letter and applicable regulations and standards to complete plan review. Please note that due to your proposed use of LNG fueled propulsion systems, MSC may identify additional detailed design requirements in areas not addressed in this regulatory design basis agreement during the course of plan review. As always, the Officer in Charge, Marine Inspection may impose additional requirements, should inspection during construction reveal the need for further safety measures or changes in construction or arrangement" (USCG letter July 1, 2011).

This is an important aspect in contracting for the first new build, or conversion, of a LNG fueled ferry in the U.S., as it is doubtful the contracting shipyard would accept the normal responsibility to build a vessel to the various rules as their responsibility. Thus, there is more cost liability in the construction, or conversion, of the first U.S. LNG fueled ferry than would be the case for a conventionally fueled ferry, or a subsequently built LNG fueled ferry.

A *Regulatory Review of Concept* was submitted to the USCG for the Issaquah class vessels in September 2011.

The IMO rules (Chapter 2, paragraphs 2.1.1 and 2.1.2), and the similar DNV rules, require something that is not normally carried out in contract design, that of a risk analysis of how the LNG fuel and storage systems affect vessel structure and other systems. The designer is to show how these risks are to be eliminated or minimized. An operating manual is required in which these risks and reactions/mitigations are to be detailed.

The reason for this additional requirement is the complexity involved in designing a fueling system with a great deal more risk than an oil fuel system. The operation of LNG fueled vessels requires greater training, critical detection systems and emergency shutdown systems that operate 100 percent of the time, and, in general, a higher level of formalized operation and maintenance.

It should also be expected that the creation of plans and specifications dealing with a LNG fueled ferry and the relevant approval process will take significantly longer for the first U.S. LNG fueled ferry than it would for a conventionally fueled ferry, or subsequent LNG fueled ferries.

B. Design Considerations

An October 2011 presentation by DNV[25] identified the main safety challenges using natural gas as marine fuel including:

- *Explosion risk.* LNG is flammable in a range of 5-15 percent mixture in the air with a temperature source of 563 deg C.
- *Low temperature of LNG.* LNG released onto normal ship steel will make that steel very brittle, which could result in cracking of the steel.
- *Gas tank large energy content.* The tank must be protected from external fire, mechanical impact, and from the ship side and bottom in the event of a collision or grounding.

Two considerations for WSF if it proceeds with detailed design are the engine room standard for its LNG vessels and the location of the LNG storage tank.

1. Engine Room Standard

There are two engine room design standards: intrinsically safe and emergency shutdown (ESD). The Glosten Associates *144-car Ferry LNG Feasibility Design Report* notes: “There are two safety categories of gas fueled propulsion systems: inherently safe or not inherently safe. An inherently safe gas engine is an engine where all of the on-engine gas supply piping is double walled pipe. Engines without the double walled gas pipe are not inherently safe. An engine that is not inherently safe must be located in an emergency shutdown (ESD) protected engine room. This means that if an abnormal condition involving a gas hazard is detected all equipment that is not explosion protected design, including the engine, must immediately shut down. This requires that all vital equipment located in an ESD protected engine room must be explosion proof. Because (the new 144-car vessel) is an almost completed detailed design and a substantial amount of equipment is located in the engine rooms, ESD protected engine rooms are not practical.”[26]

The Norwegians exceed both the ESD and inherently safe engine room requirements by placing each gas fueled engine alone in its own steel enclosed space such that a fire or explosion in that space will not affect any other space and they use double wall piping.

The consultants corresponded with a German naval architecture firm that has extensive experience with LNG fueled vessels. Marine Service indicates that they prefer a system where gas is fed to the engines through double walled fuel lines and there is a valve hood room with ESD valves that cut off the fuel supply to the engines whenever there is a leakage in the primary gas fuel line. It allows you to have a conventional engine room arrangement, while sailing on gas and having conventional equipment in the engine room with not everything being explosion proof and expensive. It is in Marine Service’s view more practical with conversions, as it allows the vessel to retain the old auxiliaries.

2. Storage Tank Location

WSF’s concept design has the storage tanks on top. All of the Norwegian LNG ferries and the new one being built in Quebec have the storage tanks in the hull. IMO is developing international rules regarding the placement of LNG storage tanks. According to the October 2011 DNV presentation one of the

[25] DNV, *Gas fuelled engine installations in ships Background, status, safety, some solutions- Interferry Barcelona- October 2011.*
[26] The Glosten Associates, *Washington State Ferries 144-Car Ferry LNG Feasibility Design Report,* July 2011, p. 4.

primary questions being addressed in the IMO review is whether LNG tanks can be safely located below deck and below passenger spaces if properly contained.

a. Topside storage tank location

The primary reason to place the storage tank topside is because there is not enough room below deck. WSF indicates that in discussions with the USCG this is their preferred location. The letter from the USCG that provides the basis for regulatory review is based on the design submitted which has the storage tank on top.

The topside arrangement raises some potential concerns. When LNG is released in a cryogenic state (-259 F) the methane vapors are heavier than air and if a tank breach occurs, a vapor cloud of methane can form which, depending on the amount of methane released, could be several ferry lengths. Ventilation systems could pull this vapor into the ferry engine rooms and passenger spaces, which in the presence of an ignition source at the right methane mix, could result in a fire. LNG released in to the atmosphere at -259 deg F will be heavier than air until it reaches a temperature of -184 deg F where it will become lighter than air. The LNG in the tanks are under 7-10 BAR of pressure (101 – 145 psi) so any release will be in the form of a jet which will quickly mix with 50 deg F air and become lighter than air allowing it to drift off and dissipate into the atmosphere.

The topside arrangement requires that the storage tank be securely mounted and able to withstand rough seas and/or a vessel collision. The cryogenic stainless steel spillway under each tank should be designed to discharge over the side of the ferry and not to impinge on the deck.

The storage tank location requires expert design of the piping to ensure that the piping can withstand movement of the vessel superstructure in extreme conditions. One option for predicting superstructure movement is to use Finite Element Analysis (FEA) to determine, with good accuracy, what movement the piping must accommodate. WSF indicates that they have multiple experts in the use of FEA analysis and will develop the design to meet or exceed all dynamic and thermal loading conditions.

Having the storage tank on top requires piping through the passenger space walls, which is not required if the storage tank is in the hull. The gas lines to each engine are being run in the existing machinery casings in double walled piping. The casings are a secondary isolation of the piping from the passenger spaces.

b. LNG Storage Tank – Hull

The primary advantage to having the storage tank in the hull is that there is less movement in the hull than on the superstructure and less piping through the passenger areas. DNV is developing revised rules for the placement of tanks in hulls under passenger spaces that would increase the separation of the tank from the hull.

The disadvantages of having the LNG storage tank in the hull are that any gas is released into a more confined space and if there were an explosion it could affect the passenger areas. Additionally, having the gas located below deck could allow it to dissipate upwards into the passenger area in the event of a leak.

3. Design Expertise

WSF has discussed the potential for designing the LNG Issaquah class retrofit in-house. For at least the first vessel, WSF should contract the work to an outside firm that has specialized expertise in LNG fueled systems design. Washington State naval architectural firms would sub-contract with firms that are experienced in the design of LNG fueled passenger vessels to meet the requirements.

C. Construction and Inspection

1. Regulatory Review

As the USCG will play a significant role in plan approval, the use of the Alternative Compliance Plan (ACP) in which the classification society takes the role of plan approval on behalf of USCG is not possible. In this case, both the classification society and USCG will have to approve construction.

ACP came about through complaints from U.S. ship owners and shipyards that the cost of dual USCG/ classification approval and inspection was one reason U.S. vessels cost more than those built elsewhere. Thus, some additional confusion and resultant cost can be expected from the dual inspection.

2. Major Conversion – Issaquah Class Vessels

Under USCG rules, if a vessel undergoes a certain level of re-design or change, it may be classified as a "major conversion". If the USCG decides that a proposed conversion is a major conversion then the ship owner is required to update the vessel to meet all current regulatory requirements. For a 30-year vessel such as the Issaquah class vessels, this could add considerable cost. Title 46, United States Code (USC), 2101 (14a) defines major conversion as an action that:

a. Substantially changes the dimensions or carrying capacity of the vessel;
b. Changes the type of vessel;
c. Substantially prolongs the life of the vessel; or
d. Otherwise so changes the vessel that it is essentially a new vessel

The legal arm of the USCG, the office involved with vessel documentation, makes these determinations. Many have resulted in prolonged legal cases and the decisions are not always consistent in the consultants' view.

3. U.S. Shipyard Experience

No U. S. shipyards have experience with the construction of LNG fueled passenger vessels, which will add risk to the project. When the U.S. built LNG carriers at General Dynamics, Newport News and Avondale shipyards, General Dynamics and Newport News hired foreign yards experienced in the LNG system installation to work together with US shipyard engineers and workers to accumulate all off the engineering and assembly experience they had gained. Avondale, to save money did not, and installed insulation on the LNG tanks incorrectly. When on sea trials, the insulation failed and the three ships valued at $500 million were determined by the USCG to be incapable of carrying LNG and therefore were considered to be constructive total losses, as it would cost as much to fix them as it cost to build them.

WSF should require the shipyard to retain someone with LNG construction experience.

4. Impact on LNG Schedule

The LNG fueled ferry construction schedule must take into account the time added for regulatory review of the design. WSF is estimating one year for regulatory review of the concept. It may also take additional time for USCG construction inspection.

One critical path consideration for the retrofit of the Issaquah class ferries is whether the USCG will decide that the retrofit is a major conversion. It will be important to get this decision before proceeding with construction of the Issaquah class retrofits.

SECTION IX. CAPITAL PROJECT COST ESTIMATE

The consultants sub-contracted with an experienced shipyard estimator and consulted with a shipyard in Norway that has experience with constructing new LNG vessels and with a retrofit of a vessel that is similar in size to the Issaquah class ferries.

The consultants' estimate the costs for the conversion of all six Issaquah class vessels in year of expenditure dollars at $143.6 million, which is 40 percent higher than WSF's estimate of $103.0 million.[27]

The new 144-car vessel cost estimate compares the existing new 144-car vessel design with an adaption of that design to a LNG fueled vessel. The consultants' estimate for the additional cost to construct a new 144-car LNG vessel is $18.9 million, which is 31 percent higher than WSF's estimate of $14.5 million in current dollars.[28] If constructed in the 2013-15 biennium, our estimate is that a new 144-car LNG vessel would cost $20.3 million more than a new 144-car diesel vessel and the comparable WSF estimate would be $15.5 million.

A. WSF Non-Vessel Costs or Project Soft Costs

Non-vessel or soft project costs are estimated as though the Issaquah class retrofit and new 144-car vessel projects were independent. If both were done, the security planning and communications costs would be a shared expense.

1. Issaquah Cass Retrofit

As shown in the exhibit below, WSF estimates that the costs for the first Issaquah class LNG conversion for non-vessel design and construction costs will be $1.7 million in FY 2012 dollars. On-going costs for subsequent vessels will be $0.3 million unless the *Evergreen State* is retained in service to cover out-of-service time. If the Evergreen State vessel is retained in service, the additional cost is $0.7 million.

[27] WSF's estimate is adjusted as explained below to include soft costs, staggering of vessel construction and inflation that were excluded from the original estimate.
[28] WSF's estimate is adjusted as explained below to include soft costs and contingency not included in WSF's original estimate.

Exhibit 20.
Issaquah Class Retrofit Project Soft Costs
(2012 $ million)

	Cost	One time
Equivalent of Waterways Suitability Assessment (WSA)	$0.6	$0.6
Training	$0.2	
Sea Trials	$0.1	
Replacement Service	$0.7	$0.7
Less: Partial de-crew of Issaquah class vessel while in the shipyard	($0.2)	
Communications consultant support	$0.1	
Staff:		
Project Manager for WSA , Transportation Tech Engineer 5	$0.2	$0.2
Communications Consultant/ Materials Designer/Web	$0.1	
Staff subtotal	$0.3	
Total Soft Costs	**$1.7**	**$1.4**
Ongoing for additional vessels after second 144-car ferry		**$0.3**
Ongoing for addition vessels until second 144-car ferry		**$1.00**

2. New 144-Car Vessel

As shown in the exhibit below, WSF estimates that the costs for a new 144-car vessel as an LNG vessel for non-vessel design and construction will be $1.1 million. The costs for sea trials would already be included in the new 144-car vessel construction budget and replacement service would not be required.

Exhibit 21.
New 144-car Vessel Retrofit Project Soft Costs
(2012 $ million)

	Cost
Equivalent of Waterways Suitability Assessment (WSA)	$0.6
Training (for LNG)	$0.2
Communications consultant support	$0.1
Staff:	
Project Manager for WSA , Transportation Tech Engineer 5	$0.2
Communications Consultant/ Materials Designer/Web	$0.1
Staff subtotal	$0.3
Total Soft Costs	**$1.1**

B. Design and Construction Cost Estimate

1. Cost Estimate Approach

a. Concept Design

The consultants' independent cost estimate is based on WSF's concept design. WSF has submitted two requests for regulatory review to the USCG: one for the new 144-car vessel and separately for the Issaquah class retrofit.

The Issaquah class retrofit request submitted to the USCG in September 2011 includes more detailed plans and engineering than were submitted with the earlier new 144-car vessel request for regulatory review. The Issaquah class retrofit drawings and accompanying calculations were used by the consultants to determine quantities and measurements used in the cost estimate for the Issaquah class retrofit. This estimate was then used to develop a corresponding estimate for the new 144-car vessel.

WSF is considering two engine options: a single fuel/LNG engine and a dual fuel (diesel and LNG) option. This cost estimate is based on the single fuel/LNG only option, which is the engine that is used in all currently operating LNG fueled ferries.

b. System Work Breakdown Structure (SWBS) Estimate

The consultants retained the services of a professional shipyard cost estimator who used an industry standard system work breakdown structure to estimate costs.

Quantities for the estimates were derived from WSF's drawings. Cost information came from vendor quotations. A shipyard labor rate of $60.00 per hour is used.[29] The SWBS estimates include:

- *Shipyard costs.* Shipyard costs for labor, material, and sub-contractors are included in the estimate.
- *Owner furnished equipment (OFE).* Historically WSF has owner supplied the propulsion systems to take advantage of federal grants. The SWBS estimate for the new 144-car vessel and the Issaquah class retrofit each include $7.7 million for propulsion system acquisition which will be owner furnished.
- *Regulatory review.* The estimates include the cost of regulatory review by DNV, estimated at $0.3 million in both estimates.
- *Outside engineering.* The estimates include an allowance for naval architectural services of $750,000 which would be contracted directly by WSF.

b. SWBS Estimate – Process

The consultants first developed the SWBS estimate for the Issaquah class retrofit using the more detailed information available from WSF's September 2011 *Request for Regulatory Review*. This estimate was refined by reviews with Vigor and with a Norwegian ferry operator and shipyard currently retrofitting a vessel that is similar in size to the Issaquah class vessels.

Vigor Review

The estimate was reviewed with the shipyard, which provided the labor rate and options for the use of internal shipyard staff and subcontractors.

Norwegian Review

Fjord 1 is converting a 20-year old diesel fueled ferry, the *Tresfjord*, to LNG. The *Tresfjord* is similar in size to an Issaquah class ferry (*Tresfjord* 318 ft. in length, an Issaquah class ferry 328 ft. in length) and has similar engine size (both about 2500 HP). The primary difference between the two vessels is that the *Tresfjord* is powered with one diesel engine powering two generators and thrusters while the Issaquah

[29] WSF studies included two shipyard labor rates. The Glosten Associates new 144-car LNG vessel estimate included a shipyard labor cost of $65 per hour. WSF's Issaquah class estimate used $72.00 per hour. On further review, WSF states that the shipyard labor rate should be $60 per hour.

class vessels have two diesel engines each powering one propeller. The *Tresfjord* had one engine compartment empty.

The retrofit, which is required by Fjord 1's contract with the Norwegian government[30], involves using the one empty engine compartment to install a 2500 HP LNG fueled engine, retaining the existing diesel engine for back-up. Both engines would be hooked through common shafting and clutches to the generators. The LNG engine will be a single fuel/LNG only engine. One LNG fuel storage tank and one LNG fueling station will be added.

The STX Langstein shipyard in Norway is doing the retrofit under contract with Fjord 1. STX Langstein has previous experience constructing LNG fuelled vessels. The *Tresfjord* is the yard's first LNG conversion project. The *Tresfjord* conversion was expected to take 6 months. The contract was awarded in January 2011 with delivery expected in June 2011. Delivery is now expected in February 2012 because of problems encountered with the originally supplied LNG valves and piping that had to be re-ordered.

The consultants sent the SWBS estimate for the Issaquah class retrofit and WSF's engineering information from the Issaquah class retrofit request for regulatory review to STX Langstein. In subsequent meetings at the shipyard, the consultants were able to obtain man-hours used by STX Langstein on the *Tresfjord*. The consultants worked with the shipyard staff to adjust the STX Langstein man-hours for the Issaquah class vessel retrofit. Adjustments were for the extra man-hours incurred on the *Tresfjord* conversion from the faulty valves and piping; differences in the storage tank location; differing lengths in LNG filling and supply to engine piping; and for differences in engine room classification.

The consultants then compared the resulting man-hour estimate with the SWBS estimate for the Issaquah class retrofit. Taking into consideration the relatively lower efficiency of North American shipyards when compared to European shipyards, the consultants' estimate approximates the Norwegian experience.

Additional Costs

Two costs were added to the SWBS estimate:

- *Shipyard profit.* The consultants were not able to get an estimate for shipyard profit from Vigor. An industry standard assumption of 7 percent was used for this estimate. The profit was applied to shipyard costs only – excluding OFE and naval architect costs.
- *Contingency.* A 25 percent contingency was applied to the estimate.

2. Issaquah Class Retrofit Rough Order of Magnitude (ROM) Cost Estimate

a. First Issaquah Vessel Retrofit

The consultants' cost estimate for the first Issaquah class retrofit in FY 2012 dollars is $22.4 million. WSF has a lower cost estimate of $16.0 million or 40 percent lower.

The primary differences in the cost estimates result from the fact that the consultants believe that a LNG retrofit is more complicated than WSF does. Our estimate includes the use of a classification society, outside design consultants, and greater shipyard supervision. WSF has based their estimate on their experience with changing diesel engines on existing vessels.

[30] The contract required a LNG fueled vessel on the route. Fjord 1 elected to do the retrofit to meet this requirement.

Exhibit 22
First Issaquah Class Retrofit ROM Cost Estimate (FY 2012 $ in millions)

	WSF	Consultant	Difference	
Design (in-house)	$0.3		-$0.3	
Design - consultant		$0.8	$0.8	
Classification		$0.3	$0.3	
Shipyard Construction	$11.1	$15.4	$4.3	
Contingency @ 25%	$2.9	$4.1	$1.3	
Soft WSF Costs	$1.7	$1.7	$0.0	
Total	**$16.0**	**$22.4**	**$6.4**	**40%**

b. Issaquah Six Vessel Year of Expenditure Estimate

The year of expenditure estimate is based on the most aggressive possible retrofit schedule for the Issaquah class vessels. It assumes an inflation rate of 3.7 percent per year for vessel construction which is the inflation rate assumed in the 2011-13 biennium budget. The estimate assumes that each pair of engines is paid for separately one year before the start of construction.[31]

Soft costs include that the *Evergreen State* is deployed as a replacement vessel through the retrofit of the second Issaquah class vessel. *Evergreen State* operation costs are not included in the estimated costs to retrofit the third through sixth Issaquah class vessels.

Under the consultants' estimate the total year of expenditures Issaquah class retrofit cost is $143.6 million. Under WSF's estimate the total retrofit cost is $103.0 million.

Exhibit 23.
Issaquah Six Vessel Class Retrofit YOE ROM Estimated Cost ($ millions)

	WSF	Consultant	Difference	%
Retrofit six Issaquah class vessels	$103.0	$143.6	$40.6	40%

[31] Engines will most likely be ordered in one or two orders with staggered delivery dates.

3. New 144-Car Vessel Estimate Rough Order of Magnitude Cost Estimate

The consultants' cost estimate for the additional cost to build a new 144-car LNG vessel is $18.9 million, which is 31 percent higher than WSF's estimate of $14.5 million. This cost estimate compares the existing new 144-car vessel design with an adaption of that design to a LNG fueled vessel.

The consultants' estimate includes the use of a classification society and differences in shipyard labor. Other differences are in the estimate of shipyard manhours given the consultants' view of the complexity of the project.

Exhibit 24.
New 144-Car Vessel LNG ROM Cost Estimate (FY 2012 $ in millions)

	WSF	Consultant	Difference	%
Design	$0.8	$0.8		
Classification		$0.3		
Shipyard Construction	$9.9	$13.1		
Contingency @ 25%	$2.7	$3.6		
WSF Soft Costs	$1.1	$1.1		
Total	**$14.5**	**$18.9**	**$4.4**	**31%**
YOE Expenditure Dollars (2013-15 biennium)	**$15.5**	**$20.3**	**$4.8**	**31%**

SECTION X. CONCLUSIONS AND RECOMMENDATIONS

This section presents the consultants' conclusions and recommendations on the questions posed in the introduction to this report.

A. Security

What, if any, impact will the conversion to LNG fueled vessels have on the WSF Alternative Security Plan?

As discussed in Section IV on security and operational planning:

- *Security and operational planning and the associated public outreach are critical to WSF's ability to operate LNG fueled vessels*.
- *The proposed approach, which assumes the USCG will allow a modification to the process it uses for safety planning for LNG terminals, is anticipated to take 18 months and cost $1.0 million.*

Consultants' Conclusion

Security and operation planning with its associated public outreach should be the next step in the consideration of LNG for WSF vessels. A final legislative decision on LNG fuel should not be made until this planning is sufficiently complete to: 1) assess the impact of LNG on the Alternative Security Plan and on WSF and Washington State Patrol staffing; and 2) gauge public reaction.

Recommendation 1. Security and Operational Planning Funding

The consultants recommend that the Legislature provide funding for security and operational planning and the associated public outreach of $1.0 million in the FY 2013 budget.

B. Vessel Acquisition and Deployment Plan

What are the implications of LNG for the vessel acquisition and deployment plan?

As discussed in Section V:

- *Retrofitting the Issaquah class vessels will have a greater impact on the vessel acquisition and deployment plan than constructing a new 144-car vessel as an LNG vessel*. The retrofits cannot begin until the fall of 2014 following the return of the Super class *Hyak* to service from its major renovation. If the Issaquah class retrofits begin before the second new 144-car vessel is in the fleet, WSF plans to retain the *Evergreen State* in service to provide coverage. If not for the retrofit of the Issaquah class vessels, the *Evergreen State* would retire when the first new 144-car diesel fueled ferry comes on line in 2014.
- *Once a second new 144-car vessel is in the fleet, WSF can both retrofit the Issaquah class vessels and retire the Evergreen State.* To avoid disrupting service during the peak summer months, WSF plans to retrofit one Issaquah class vessel per year taking the vessel out-of-service during the fall through early spring. It would therefore take at least six years to complete the full retrofit of the Issaquah class vessels.

- *Delaying the delivery of the second new 144-car vessel by one year to accommodate its conversion to LNG will delay the planned service improvements and retirement of the Hiyu* and will require the Evergreen State to stay in service if WSF proceeds with the retrofit of the Issaquah class vessels.
- *Designing a new 144-car vessel as a LNG fueled vessel could be considered in the context of the next planned procurement of five new 144-car vessels starting in 2025.* If funding were available, a new 144-car LNG vessel could be viewed as the first of six such vessels.

Consultants' Conclusions

- **The decision whether to build a new 144-car vessel as a LNG fueled vessel should not be made until the security planning is complete.** Assuming funding in FY 2013, the security planning could be completed by January 1, 2014 at which point a decision could be made on whether to proceed with the new 144-car vessel as a LNG fueled vessel. If funded in FY 2014, the new 144-car LNG vessel could potentially come on line in 2017.
- **A new 144-car LNG vessel should be purpose built as a LNG vessel.** The most economical action would be to consider the first new 144-car LNG vessel as part of a series of six such vessels or so many as the Legislature decides to fund. This would allow WSF to acquire a purpose built LNG design. A purpose built design would result in safety improvements from the engine room being designed specifically for LNG. It would also allow WSF to achieve the economies of scale of purchasing more than one vessel at a time.
- **Retrofitting the Issaquah class ferries will take at least six years and require the Evergreen State to stay in service unless a second new 144-car vessel comes on line.** Under the most aggressive schedule the retrofitted Issaquah class vessels would come on line between 2015 and 2020. The *Evergreen State* would have to remain in service past its projected 2014 retirement for up to six additional years at which point it will be 66 years old. Funding for preservation of the *Evergreen State* is not included in the 2011-27 16-year financial plan because it is expected to retire.

Consultants' Recommendations

Recommendation 2. New 144-Car Vessel

The consultants recommend that the Legislature proceed with construction of the second new 144-car vessel as a diesel fueled vessel, with delivery in 2015 if funding is available, if it is more important to improve service on the schedule anticipated in the WSF Long-Range Plan than to potentially reduce operations costs. If the Legislature considers construction of a LNG fueled vessel it should consider the investment only after the completion of security planning and in the context of the planned procurement of five new 144-car vessels to allow for the acquisition of a purpose built LNG design and potential economies of scale in ship building.

Recommendation 3. Issaquah Class Retrofit

If the Legislature considers retrofitting the Issaquah class vessels, it should do so only after the completion of security planning. Design and construction should follow recommendations 4 -7 below. The legislature should also recognize that funding will need to be provided for preservation of the *Evergreen State*. WSF estimates preservation needs for the *Evergreen State* to be an additional $0.4 million until 2018, at which point it would potentially need propulsion controls replaced at a cost of $5.7 million.

C. LNG Design and Construction

What design and construction constraints should be considered in making LNG decisions?

As discussed in Section VI on vessel design and construction:

- *The USCG design and construction review process, which will be in addition to the security planning requirements, will take longer than normal.* This longer time period will occur because the USCG does not have LNG fueled passenger vessel rules and because it is likely that WSF would be one of the first, if not the first, to construct or retrofit a LNG fueled passenger vessel in the United States.
- *There is international regulatory uncertainty.* The IMO is in the process of revising its rules and has extended the deadline for completing their rules until 2014.
- *There are safety considerations in LNG design that are different than for a diesel fueled vessel.* These safety concerns include explosion risk, low temperature of LNG, and the large gas tank energy content. Two design considerations are the engine room standard, which can be either the emergency shutdown system that exists in all the Norwegian vessels and automatically shuts down any areas with a gas leak, or the inherently gas safe design planned by WSF that requires all gas supply piping to be double walled, and the location of the storage tank.
- *There is limited U.S. design or construction experience with LNG fueled passenger vessels.* All of the experience is elsewhere in the world. The Norwegians have the most extensive experience.
- *Major conversion.* The USCG could decide that the Issaquah class retrofits are major conversions, which would make the retrofit prohibitively expensive because the vessel would be required to meet all USCG equipment and ADA regulations as if it were a new build.

As discussed in Section VI on diesel and LNG fuel:

- *The fuel contract should be let before construction of the vessels.* This will allow the motors to be tested during the construction process with the actual fuel to be used in operation and it will ensure supply.

Consultants' Conclusions

- **Safety in the design and construction of LNG vessels is of paramount importance.** Other nations, particularly Norway, and the classification societies can help overcome the lack of U.S. experience with LNG fueled passenger vessel design and construction. If a vessel is constructed to class it means that the classification society guidelines have been followed and the classification society has inspected the construction and certified it.
- **The pre-design process will allow the Legislature to review the design options before making a final decision.** The Legislature requires that all vessel improvement projects and vessel preservation projects over $5 million include a pre-design study (ESHB 3209 adopted in the 2010 session). The pre-design study can provide the Legislature with additional information prior to appropriating funds for construction of a LNG fueled vessel.
- **A major conversion decision should be sought from the USCG prior to starting construction.** If the USCG decides that the Issaquah class retrofits are major conversions, it could make the retrofit prohibitively expensive because the vessel would be required to meet all USCG equipment and ADA regulations as if it were a new build.

Consultants' Recommendations

Recommendation 4. Design

If the Legislature decides to pursue a LNG fueled vessel, the Legislature should provide funding and require WSF to:

- Contract with an outside design firm that has previous LNG fueled passenger vessel design experience rather than design the LNG vessels in-house. As a practical matter Washington state naval architects would have to sub-contract with firms that are experienced in the design of LNG fueled systems to meet this requirement.
- Design LNG vessels to a classification society rules (which could be DNV or another classification society) and have them classed during construction.

Recommendation 5. Construction

The Legislature should consider amending the bid process to require bidders to include an expert from a shipyard with LNG fueled vessel construction experience in their bid that WSF could qualitatively evaluate.

Recommendation 6: Regulatory Determination for Issaquah class retrofit

WSF should request a ruling from the USCG on whether the Issaquah class retrofits will constitute a major conversion before proceeding with more detailed design and construction.

Recommendation 7. Construction

The LNG fuel supply contract should be in place before the shipyard construction contract is let. This will allow the engine to be tested with the actual LNG fuel that will be used in operation and ensure supply and price.

D. Vessel Operation

How will LNG fueled vessels affect bunkering and other WSF operations?

As discussed in Section VII on vessel bunkering and maintenance:

- *LNG bunkering is anticipated to be more complex than with diesel fueling which WSF will need to take into account in its operational planning*.
- *Maintenance and staffing costs are not anticipated to increase although the USCG could require additional staffing with its Certification of Inspection*.
- *Given the complexity of the systems involved WSF should consider retaining a classification society to inspect and report on the condition of the LNG vessels for at least the first 10 years of their operation.* The Norwegian ferry operators interviewed have maintained classification services for the operation of their LNG vessels even though, as is the case with WSF, they do not maintain classification services for the operation of their diesel vessels. The vessels discussed are two to four years old and those interviewed indicated that they did not plan to keep classification for the life of the vessel but would phase it out at some point.

Consultants' Conclusions

- **Bunkering will be more complex than diesel but this should not pose a problem for WSF other than requirements that may be part of the security plan.** Bunkering is more complex but with adequate training WSF should be able to accommodate it. However, bunkering requirements may also be a part of the safety plan and those requirements may add additional costs that cannot yet be anticipated.
- **Maintenance and staffing costs should be the same as for the diesel-fueled vessels.** This is consistent with the experience in Norway. However, staffing costs may change when the USCG issues the Certificate of Inspection.
- **The cost of classification services at $15,000 per year per vessel would be a worthwhile investment.** Maintaining classification services for LNG vessels will help ensure safe operation.

Consultants' Recommendation 8. Operation Classification

WSF should maintain classification services for the operation of their LNG vessels during at least the first 10 years of operation**.**

E. Business Case

What is the most cost-effective scenario to introduce LNG fueled vessels to the WSF fleet considering both operation cost savings and capital project costs?

Determining the most cost-effective scenario to introduce LNG fueled vessels to the WSF fleet hinges in part on the security planning to be undertaken and the decision the Legislature makes on whether to delay construction of a new 144-car vessel to allow it to be constructed as a LNG fueled vessel. Also key is the decision whether to retain the *Evergreen State* in order to allow for the retrofit of the Issaquah class vessels.

As discussed in Section VI on fuel costs and Section IX on capital project cost estimate:

- *There are substantial potential fuel savings from building a new 144-car LNG vessel and/or from retrofitting the Issaquah class vessels.* For one new 144-car vessel the savings is between $86 million and $120 million over the life of the vessel. For the Issaquah class vessels the savings are between $140 and $191 million over the life the six vessels.
- *The capital cost for the conversion of the Issaquah class vessels is close to the fuel cost savings without taking into account the potential cost to preserve the Evergreen State.* The consultants' estimate the costs to convert all six Issaquah class vessels in year of expenditure dollars is $143.6 million, which is 40 percent higher than WSF's estimate of $103.0 million. This does not take into account any potential costs to preserve the *Evergreen State*. It does include costs to operate the *Evergreen State* for the first two retrofits. The net present value of the Issaquah class investment under these assumptions is negative except for the case that assumes the lowest projected fuel cost and the lowest projected vessel cost in which case the net present value is positive.
- *The investment in LNG fuel for the second new 144-car vessel is cost-effective.* The consultants estimated the additional cost for the construction of the second new 144-car as an LNG vessel in the 2013-15 biennium is $20.3 million and the comparable WSF estimate is $15.5 million with

fueling savings of between $86.3 million and $120.0 million. The net present value of the new 144-car vessel is positive under all scenarios.

- *There are potentially large savings from retrofitting the three Jumbo Mark II vessels.* Retrofitting these three 202-car vessels which use 27 percent of WSF's fuel could result in savings of between $355 and $494 million in fuel costs over the life of the vessels.
- *There is recent activity in the availability of CNG that may make it more viable as a marine fuel source*.

Consultants' Conclusions

- **The security planning and outreach costs for LNG are substantial and the more vessels these costs cover the more cost effective the investment will be.** The financial analysis is independently done for the Issaquah class retrofit and for the new 144-car vessel. But the one-time costs for security planning will not be repeated if both projects are done or if the Legislature eventually funds more LNG fueled vessels.
- **The Issaquah class retrofit is not a sound economic investment as the project is now structured.** The retrofit would be more viable after a second new 144-car vessel is on line because the project would not have to bear the costs of operating the *Evergreen State*. Depending on when the new 144-car vessel comes on line, the remaining life of the Issaquah class vessels might be reduced from that contemplated in the current economic analysis.
- **The investment in a new 144-car LNG vessel is economically viable.** The investment would be even better if it is done for a class of LNG vessels with the consequent economies of scale from purchasing more than one vessel at a time.
- **It would be worthwhile to invest in an exploration of the potential retrofit of the Jumbo Mark IIs.** The potential fuel savings are sufficiently large to justify the cost of developing a concept design to see if the Jumbo Mark IIs can be retrofit.
- **Development with CNG should be tracked to see if it becomes a viable option for marine fuel for WSF.** CNG may have some advantages that should be considered including a local supply and potentially less hazardous operation. However, the operational implications of daily fueling would have to be considered.

Consultants' Recommendation
Recommendation 9. Pre-Design and Business Case Funding
At the same time WSF is engaged in security planning, the Legislature should provide funding for WSF to develop a more refined business case and pre-design report for the LNG conversion which would consider the potential to retrofit the Jumbo Mark II vessels and provide updated CNG information.

APPENDIX A. INTERNATIONAL AND NATIONAL LNG FUEL PRICE FORECASTS

International

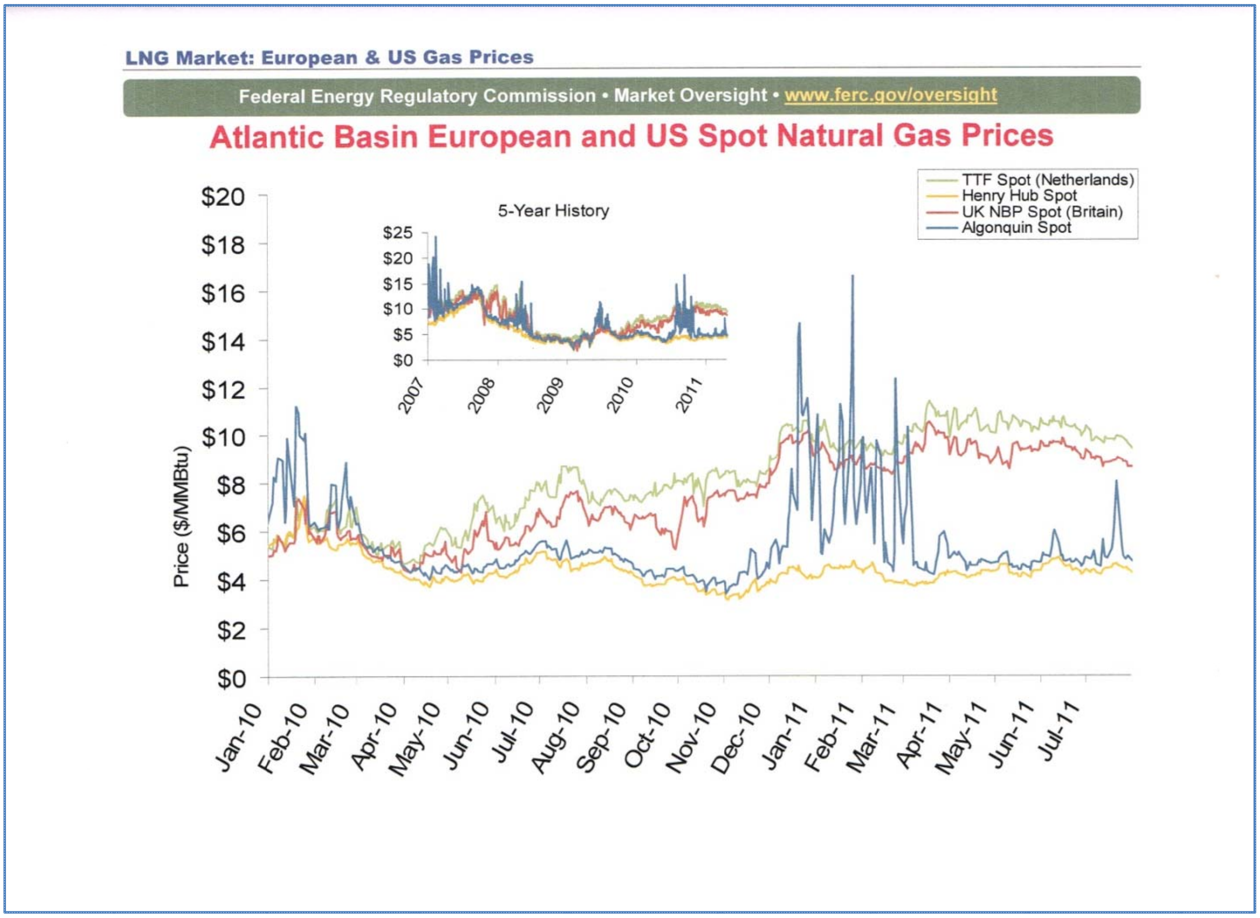
The economics of marine LNG use for WSF will be different than Norway's because LNG is much less expensive in the U.S. and, unlike Norway, the cost of natural gas does not track with the cost of petroleum. The difference in LNG cost, which is based on the spot price of natural gas, between Europe and the United States over the last five years is shown in the exhibit below.

A spot price is the current price at which a particular commodity can be bought or sold at a specified time and place. The prices in the exhibit below are for two European trading points (TTF Netherlands and UK NBP Spot Britain) and two U.S. (Henry Hub and Algonquin Spot).[32] While the Algonquin Spot price in the northeastern U.S. sometimes spikes above the European prices, the Henry Hub price for LNG delivered to Sabine Terminal in Louisiana is always lower. The Henry Hub price is the more important price point as it is the price used on the New York Mercantile Exchange and the forecasts for natural gas prices in Washington State are premised on the Henry Hub price.

[32] TTF Spot (Netherlands) is the Title Transfer Facility (TTF) is a virtual trading point for natural gas in the Netherlands, which allows gas to be traded within the Dutch network.UK NBP (Spot) Britain is the National Balancing Point, commonly referred to as the NBP, is a virtual trading location for the sale and purchase and exchange of UK natural gas. It is the pricing and delivery point for the Intercontinental Exchange (ICE) natural gas futures contract. Henry Hub Spot is the pricing point for natural gas futures contracts traded on the New York Mercantile Exchange. It is a point on the natural gas pipeline system in Erath, Louisiana owned by Sabine Pipe Line LLC. Algonquin Spot United States is the point for natural gas delivered to the Algonquin City-Gates, used for commodities trading. Algonquin City-Gates is in Massachusetts.

Exhibit A-1.
World LNG Fuel Price Comparison

This exhibit shows the difference in natural gas prices between Europe and the United States. The Henry Hub and Algonquin lines are United States prices and TTF and UK NBP lines are Europe.

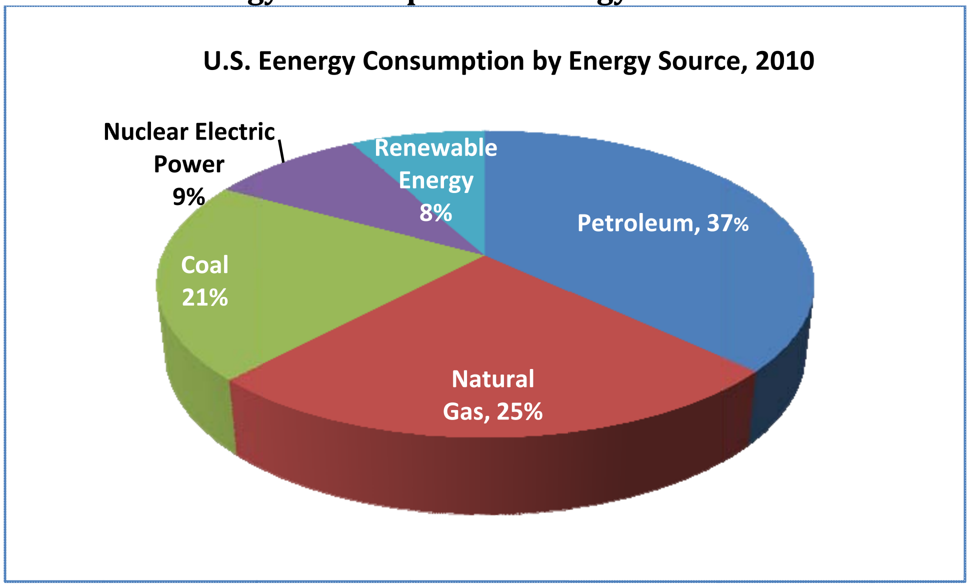


Source: Federal Energy Regulatory Commission

B. National Outlook for Natural Gas Supply and Price

Projections by the U.S. Energy Information Administration and other independent analysts all suggest that the United States' supply of natural gas is robust. Natural gas provides 25 percent of the United States total energy supply.

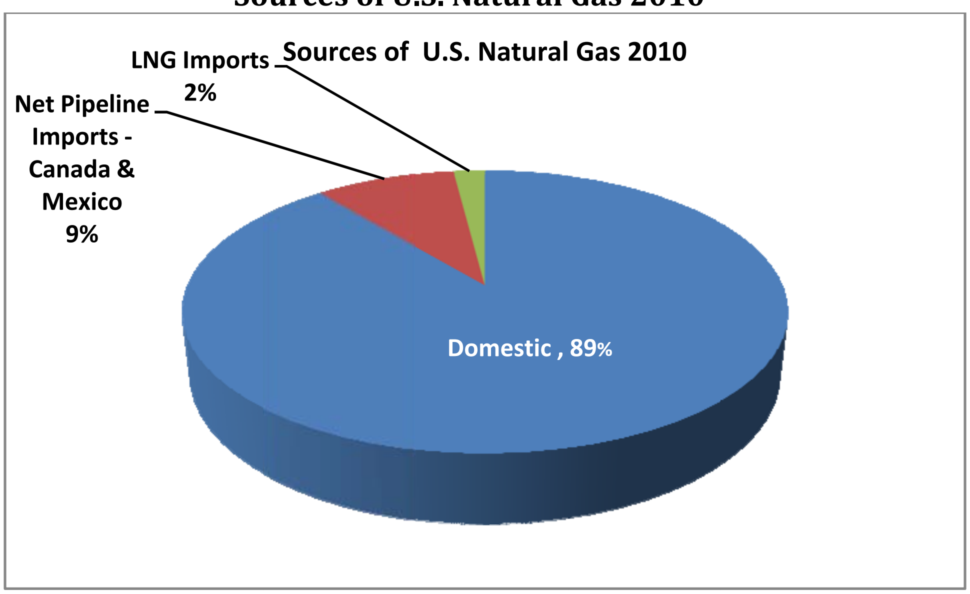
Exhibit A-2.
U.S. Energy Consumption of Energy Source 2010



Source: U.S. Energy Information Administration

Most of the natural gas consumed in the United States is produced in the United States. Some is imported by pipeline from Canada and Mexico, with the same pipelines used for exports of United States natural gas to these countries. Canada accounts for 99 percent of our net imports and Mexico, to which we export more natural gas, 1 percent. A small portion of our natural gas, 2 percent in 2010, is shipped to the United States as liquefied natural gas (LNG) primarily from Trinidad and Tobago. LNG imported to the U.S. is usually regasified at the import facility.

Exhibit A-3.
Sources of U.S. Natural Gas 2010



Source: U.S. Energy Information Administration

Forecasts for the nation's future natural gas supplies project a stable and growing source of domestic supply with relative price stability. "The recent emergence of substantial new supplies of natural gas in the U.S. primarily as a result of the remarkable speed and scale of shale gas development has heightened awareness of natural gas as a key component of indigenous energy supply and has lowered prices well below recent expectations. Instead of the anticipated growth of natural gas imports, the scale of domestic production had led producers to seek new markets for natural gas, such as an expanded role in transportation."[33] Shale gas has been discovered in the Mountain West, the South and throughout the Northeast's Appalachian Basin.

The U.S. Energy Information Administration Outlook 2011 projects as its reference case (i.e. the most likely scenario) that U.S. natural gas production will increase almost fourfold from 2009 to 2035, with total domestic production growing from 21.0 trillion cubic feet in 2009 to 26.3 trillion cubic feet in 2035. Shale gas is anticipated to make up 47 percent of the total natural gas production in 2035, up from its 16 percent share in 2009. Under this scenario U.S. imports of natural gas are expected to decline from both net pipeline imports and LNG shipments.

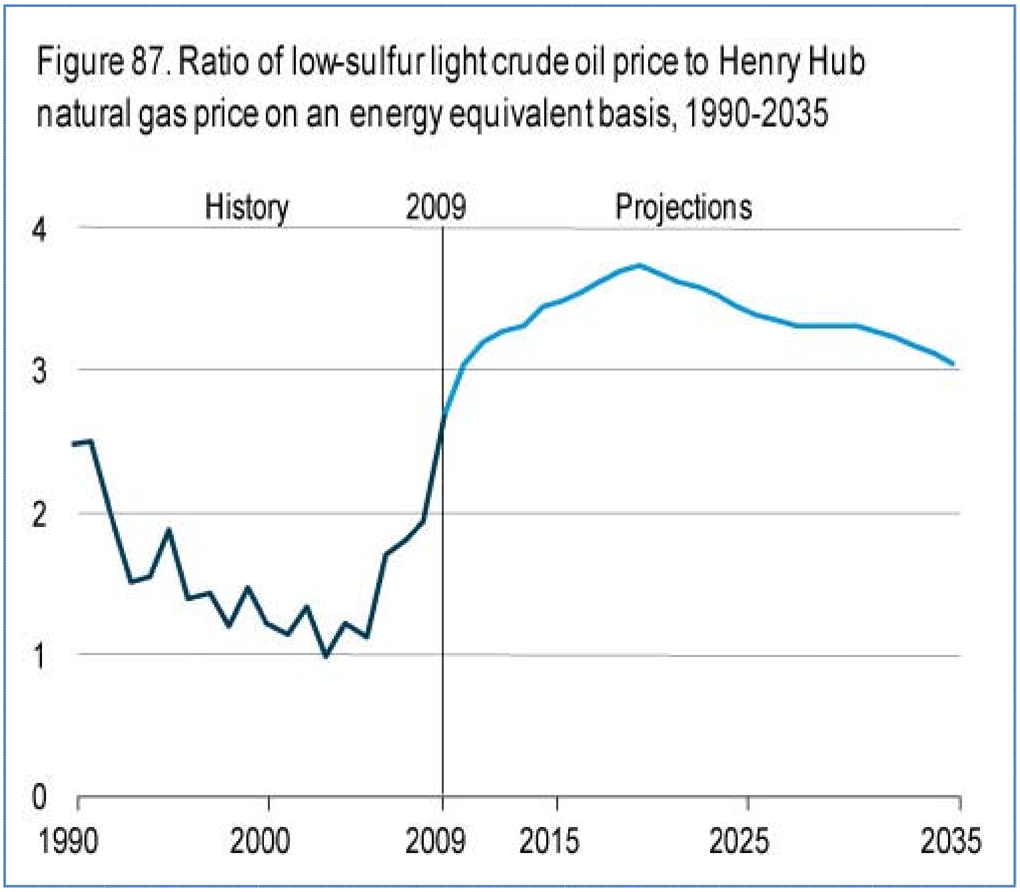
As a consequence of the increase in domestic natural gas production, the U.S. government is allowing LNG import terminals to also export domestically produced LNG. In May 2011 the Department of Energy provided provisional authorization for the Sabine Pass LNG Terminal to export LNG. "This is the first long-term authorization to export natural gas from the lower 48 states as LNG to all U.S. trading partners." [34] The Lake Charles and Freeport LNG import terminals are under regulatory review to export domestic LNG. The LNG terminal at Kenai Alaska is the only existing LNG terminal that has exported LNG but it has been shut down.

As shown in the exhibit below, prices for natural gas are anticipated to remain relatively low compared to low sulfur diesel. "Unlike crude oil prices, natural gas prices do not return to the higher levels recorded before the 2007-09 recession. Although some supply factors continue to relate the two markets loosely, the two do not track directly."[35]

[33]MIT*, Natural Gas Outlook* 2011, pg. 1.
[34](www.fossil.energy.gov/news/techlines/2011/11023-DOE_Approves _LNG_Export
[35] U.S. Energy Information Administration, *Energy Outlook 2011*, pg 38

Exhibit A-4.
Ratio of ULSD to Natural Gas Prices 1990-2035

This exhibit shows that prior to 2009 ULSD prices were the same as or up to 2.5 times higher than natural gas prices. Projections through 2035 are that ULSD prices will be at least 3 times higher than natural gas. The projections are on an energy equivalent basis, which means that they are adjusted for the higher volume of natural gas needed to generate the same amount of energy.



Source: U.S. Energy Information Administration, 2011 Energy Outlook

The *Energy Outlook 2011* alternatives to the reference case consider variables related to the production of shale gas, the rate of economic growth, and the rapidity of change in technology for gas extraction. In the five scenarios considered, the price of natural gas ranged from 31 percent higher (low shale gas production, slow economic growth, and slow technology) to 24 percent lower (high shale gas production, high economic growth, and rapid technology) based on assumed price elasticity in electrical power and industrial uses of natural gas. In all scenarios the price of natural gas remains lower than diesel.

APPENDIX B. IMPACT OF LNG USE ON VESSEL SPEED, PERFORMANCE

1. Weight and Draft

The empty weight (lightship) of an LNG fueled vessel will be about 150 tons heavier than the presently designed diesel oil fueled main engine 144. Thus, the lightship weight will be increased by about 4 percent. As LNG fuel is about half the specific gravity of diesel oil, there are some reductions in fuel weight; however, overall, it appears the LNG fueled ferry will operate slightly deeper than the draft conditions presently estimated for the 144 diesel fueled design. The amount of draft overage depends on the load of passengers and cars, the route and other factors.

It is estimated that in all of the operating conditions possible that this additional draft would be about 1.5 to 2.0 inches or about 60 to 80 tons more displacement. This amount is considered to have no major effects on performance.

2. The Service Life Margin

The service life margin is an allowance for additional weight that might be added to a vessel during its life and allows weight modifications from regulatory changes, or other operating necessity, to be accommodated within the vessel without exceeding maximum draft, or stability limits.

The service life margin for the diesel fueled 144 the draft amounts to 338 tons and increases the design draft by about 8 inches. For the LNG fueled 144 design, you must add the 150 tons (above) and the 338 tons service life margin to get the LNG fueled 144 service life margin. This equates to about 500 tons additional displacement as an allowance, or about a 14% increase in displacement.

The worse case of a fully loaded LNG fueled 144, with service life margin applied, results in a departure draft of 17.6 feet and an arrival draft of 17.34 feet which is a 1.7 inches greater than the diesel fueled main engine 144, as presently designed. The consultants do not consider the differential between the diesel oil fueled and LNG fueled 144 to have a major effect on performance.

3. Power Installed for Propulsion

The present 144 diesel fueled main engine design shows 6000 HP as the installed power.

Both the Rolls Royce and Wärtsilä LNG fueled main engines provide about the same installed power, at about 5900 HP for the Rolls RoyceC26.33L9PG engine and 6168 HP for the Wärtsilä 6L34DF engine.

4. Speed

The models tests for the 144 design, carried out at SSPA, show, for a draft of 16.4 feet, that 4960 HP (3700 MW) of power is required for 17kts (the design speed) on trials (clean bottom, light sea). This equates to 82 percent of the installed power for propulsion.

Using 100 percent of the power installed for propulsion (6000 HP) would allow a speed of about 18knots, in the same trial condition. The consultants do not have model test data based upon 17+ feet of draft, so we have estimated that if there is sufficient installed power in the present diesel fueled 144 design to make the 17 knot design speed, including the effects of the Service Life Margin, then the LNG fueled option should perform the same.

5. Stability

The conversion of the 144 from diesel fueled to LNG fueled raises the center of gravity of the 144, in all cases. This has the effect of allowing the ferry to roll and heel slightly further in equivalent seas, or wind; however this effect also gives a motion that should be slightly easier (more comfortable).

There is not much additional wind bearing area of the above deck mounted LNG equipment as the equipment is mounted behind of existing structure.

In every case, the LNG fueled ferry will be considered to be well within the “safe area” as dictated by USCG stability requirements.

On most routes, the above effects would be undetectable.

6. Steering

The consultants think the small draft change and minimal added wind area will have not any effect on steering for the LNG fueled ferry when compared to the diesel fueled ferry. Turning circles should be the same for both.

7. Reliability of Vessel Operation

WSF ferries have engines and propellers at each end and when transiting from one terminal to another, the engine in the bow is run at very low speed (almost idle speed) so that it does not create propeller drag. To not create drag, this forward propeller must be operating in reverse. For a controllable pitch (C/P) propeller ferry such as the new 144-car vessel will have and the Issaquah class vessels have, the engine is still run forward, but the pitch of the propeller is reversed. When the ferry approaches the arrival terminal, rather than rely on the stern engine being quickly reversed to provide stopping power, the bow engine is increased in speed, quickly, which slows down the ferry. This requires the fixed pitch propeller ferry to stop the forward engine and to reverse it, before increasing the power to stop. For the C/P propeller, the engine does not have to be stopped, but the propeller must be reversed in pitch. The response of this bow engine is an important safety factor as reversing stern engines, gears or even C/P propellers, just in time, has not always happened; the method outlined is much safer. The single fuel/LNG only engine would meet this requirement reliably. It is less clear whether the dual fuel engine would meet this requirement reliably.

APPENDIX C. WASHINGTON STATE FERRIES RESPONSE

Washington State Department of Transportation

Paula J. Hammond, P.E.
Secretary of Transportation

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David H. Moseley
Assistant Secretary for
Washington State Ferries

January 3, 2012

Ms. Mary Fleckenstein, JTC Coordinator
Joint Transportation Committee
3309 Capitol Blvd SW
PO Box 40937
Olympia, WA 98504-0937

RE: Response to Cedar River Group Study
"Evaluating the Use of Liquefied Natural Gas in Washington State Ferries"

Dear Ms. Fleckenstein:

At the request of the Joint Legislative Transportation Committee (JTC), the Cedar River Group (CRG) has prepared a study titled, "Evaluating the Use of Liquefied Natural Gas in Washington State Ferries". The study summarizes its recommendations as follows:

"This report recommends that the Legislature consider transitioning from diesel fuel to liquefied natural gas for WSF vessels, making LNG vessel project funding decisions in the context of an overall LNG strategic operation, business and vessel deployment and acquisition analysis."

The Washington State Department of Transportation, Ferries Division (WSF) agrees with this recommendation. As the report details, we believe the transition to LNG is essential for financial and environmental reasons.

The report details nine separate recommendations. Below we will respond to each of these recommendations.

Recommendation 1 - Security and Operational Planning Funding
WSF agrees that the Legislature should provide funding for security and operational planning and the associated public outreach. We are currently developing a work plan and schedule for a security and operational planning process and will have this available for legislative review early in the session.

Washington State Ferries

January 3, 2012
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Recommendation 2 – New 144-Car Vessel
WSF agrees that the second new 144-car vessel should be a diesel fueled vessel.

Recommendation 3 – Issaquah Class Retrofit
WSF agrees that consideration of retrofitting the Issaquah class vessels should not be made until the completion of the security and operational planning process. If the decision is made to proceed with retrofitting the Issaquah class vessels, the best construction sequencing and continued use of the *Evergreen State* vessel should be made at that time.

Recommendation 4 – Design
While we are in conceptual agreement with this recommendation, WSF would offer a slightly modified approach. WSF agrees that it would be useful to use DNV or another classification society in the detail design process for the LNG retrofits. The use of a classification society should continue throughout the design process up to and including design acceptance and approval by the United States Coast Guard (USCG). WSF believe we should reserve judgment on whether it is beneficial to continue to classify the vessel until after design development has been completed and approved.

Recommendation 5 – Construction
WSF agrees with the benefits of having construction expertise in LNG fueled vessels. In concept, WSF will develop an RFP to purchase the LNG engines and LNG tanks and delivery system. As part of this RFP, WSF will require the contractor to provide integration expertise and assistance throughout the retrofit construction and will have responsibility for the successful integration of the propulsion system.

Recommendation 6 – Regulatory Determination for Issaquah Class Retrofit
WSF agrees with the need to obtain a ruling from the USCG on whether the Issaquah class retrofit would constitute a major conversion. WSF will formally request this with the Marine Safety Center.

Recommendation 7 – Construction
WSF agrees that a LNG fuel supply contract should be in place before the shipyard construction contract is awarded.

Recommendation 8 – Operation Classification
As noted in our response to Recommendation 4, WSF believe that this decision should be reserved until the detail design development process has been completed and approved. We will be in a better position to analyze the usefulness and benefits of this expenditure at that time.

Recommendation 9 – Pre-Design and Business Case Funding
WSF agrees that, at the same time that we are engaged in the security and operational planning process, the Legislature should provide funding for WSF to develop a more refined business case and pre-design study.

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Page Three

WSF would like to make a final comment on the construction estimates provided in the report. WSF continues to believe that the cost of retrofitting Issaquah and 144-car vessels is much closer to our estimate provided in the report ($16.0 million for Issaquah/$15.5 million for 144-car) than to the consultant's sub-contract estimator's cost ($22.4 million for Issaquah/ $20.3 million for 144-car). As can be seen in the cost estimate comparison provided on pages 53 and 54 of the report, the vast majority of the estimated differences is in shipyard construction and contingency costs. This is driven largely by the very high estimate of man-hours required to complete the construction work by the consultant's estimator (112,000 man hours) verses WSF's estimate (34,000 man hours) and by the estimate of steel needed to complete the retrofit. The estimator provided an estimate of 158,000 pounds of steel verses WSF's estimate of 14,800 pounds of steel. Because of the large discrepancy in steel work, other associated work related to insulation, paint and preservation resulted in those being overestimated as well.

We believe our estimates of man-hours and use of steel is much closer to what the actual cost will be. WSF has a proven track record in construction cost estimating. In recent construction estimates for the 144-car vessel and the Keller ferry the WSF estimate was very close to the final bid price. The 144-car ferry was within 2% of the awarded contract and the Keller ferry was within 1% of the awarded bid. In addition, WSF has installed new engines in all six of the Issaquah class vessels and has this experience to draw on. While WSF acknowledges that a LNG retrofit is somewhat more complex than our previous experience, the engine work, alarm and monitoring and engine control work is very similar. We do not believe the installation of the LNG fuel system justifies such high assumptions on man-hour and steel use. We believe our estimates take that additional complexity into consideration.

Sincerely,

David H. Moseley
WSDOT Assistant Secretary
Ferries Division

cc: Kathy Scanlan, CRG

WASHINGTON STATE FERRIES

LNG BUNKERING PROCEDURE

FOR

ISSAQUAH CLASS FERRIES

REV	--			
DATE				

Background

Our globe requires sustainable transportation and customers are demanding more environmentally sound transportation. New regulations regarding ship emissions are at the horizon. Actions soon need to be taken; the question is only which direction to choose.

LNG (Liquid Natural Gas) as ship fuel is an option to meet future regulations regarding SOx and NOx emissions set up by international authorities. In 2015 the allowed SOx (Sulphur oxides) emissions from ships sailing within ECA (Emission Control Area) will drastically be reduced. Since the sulphur comes purely out of the fuel, a change of fuel away from high sulfur fuels. Low sulfur fuels will then most probably be more sought after and therefore more costly, which will make LNG more cost effective as a bunker fuel.

In 2016 the new NOx rules are put into force by the IMO (International Maritime Organization), which means very low levels of NOx emissions are allowed, the so called Tier III levels. These regulations only concern ships built after the new regulations are put into force. With LNG as fuel it is possible to comply with these rules at the present time without any exhaust after treatment.

The environmental benefits of LNG are even higher than the aforementioned requirements. Today, particulate and carbon dioxide emissions are not regulated for marine transportation. There are indications that restrictions will be introduced even in this area which makes LNG an even better alternative fuel for shipping. Since natural gas has the same components as biogas (a form of natural gas produced from renewable products), it is possible to switch LNG for LBG (Liquid Bio Gas). LNG can therefore also serve as a bridge to more use of renewable LBG.

With LNG or LBG as ship fuel, there will be almost no emissions of SOx (sulphur oxides) and particulates, very low emissions of NOx (nitrogen oxide) and reduced emissions of CO_2 (carbon dioxide). If LBG is used the CO2 net value levels are very low.

LNG is a new product for the marine industry worldwide and a full distribution network is not currently available. However, there are a number of Peak Shaving facilities in the Northwest that can supply LNG to our ferries by truck. The peak shaving facilities are liquefaction facilities that take natural gas from the gas line, liquefy the gas and store the LNG in large storage tanks. Puget Sound Energy has LNG delivered from a plant in Plymouth, Washington to a facility in Gig Harbor where the LNG is stored in tanks and released into the pipe line to handle excess demand in cold weather.

LNG as bunker fuel is not a new invention though; today LNG is used as main propulsion fuel for some Norwegian ferries and offshore vessels. The bunkering is done by truck or directly from a shore based terminal, a proven technology that works well in Norway.

The build-up of an LNG supply chain based on truck to ship bunkering is of paramount importance for LNG to become a real alternative to the use of marine diesel fuel on board Washington State Ferries. Nevertheless, there are no existing guidelines for the procedure of truck to ship bunkering of LNG today.

The following procedure has been developed based on the project to develop a ship to ship bunkering procedure that was initiated by the Svenskt Marintekniskt Forum and carried out together with FKAB Marine Design, Linde Cryo AB, Det Norske Veritas AS (DNV), LNG GOT and White Smoke AB. The procedure developed by the Svenskt Marintekniskt has been approved in principle by DNV.

Objectives

The objective of this procedure aims at establishing a safe and time efficient truck to ship bunkering procedure for LNG, encompassing the entire bunkering operation, both the operational bunkering process and the technical solutions needed.

Since there are no existing guidelines for LNG bunkering truck to ship, the project will try to establish a procedure that can be approved by the US Coast Guard for safe and time efficient bunkering of LNG.

Introduction

The Washington State Ferry Issaquah Class vessels operate in Puget Sound carrying passengers and vehicles across the sound and bays including routes from Seattle to Bremerton, Vashon to Fauntleroy and Clinton to Mukilteo. The short routes are all well suited to use LNG as main fuel. The Issaquah Class ferry operating between Seattle and Bremerton is used as the reference vessel throughout this procedure.

It is assumed that the bunkering will take place in Bremerton, a port within an urban/industrial area. The bunkering will take approximately one hour and be accomplished during their night tie-up. This means that the requirements on the ship and truck are strict both for bunkering speed as well as for safety aspects.

The Ferry will need both LNG and diesel oil. Even if the engine is a “Gas-Only” engine, the Ferry will still use the existing ship’s service diesel generators for vital and hotel loads. At the present time the WSF fleet burns ultra-low sulfur diesel fuel with a blend of five percent biodiesel for both power generation and main propulsion engines. The Ferry will need both diesel fuel and LNG delivered to the vessel by truck. The diesel fuel delivery will not be done during any sequence of the LNG bunkering operation.

The amount of LNG bunker fuel delivered by truck is 10,000 gallons (38 cubic meters). The maximum bunkering time is set to 50 minutes. All the Issaquah Class vessels are currently fueled by truck. The frequency of the delivery will be dependent on the route, but the range is from once per week to twice per week on the routes presently served by the Issaquah Class vessels.

Risk Assessment

In accordance with the Concept of Operations (CONOPS), Sections 8 and 9, WSF will conduct a thorough safety and security assessment before any final decisions are made regarding the conversion of Issaquah class vessels to LNG. The assessment will use a methodology that meets generally accepted risk-based decision-making industry standards and will be as objective and transparent as possible. The assessment will outline conditions that could result in a release of LNG be it accidental (e.g., collisions, groundings, equipment failure, etc.) or intentional (e.g., terrorist act, sabotage, etc).

Rules and Guidelines

During bunkering there are certain regulations to consider. Local authorities and the responsible port need to permit LNG bunkering at the chosen location. In this study the following national rules and guidelines has been used:

- Port Regulations for the Port of Seattle
- National Fire Protection Association, NFPA-57
- Code. 2002 Edition Rules for the truck.
- IMO IGF Interim guidelines – (International Gas Fuel), Rules for the Ferry
- 33 CFR127 Waterfront Facilities Handling LNG

For the ferry using LNG as bunker fuel, the IGF interim guidelines are the regulations that have to be used. The IGF guidelines are called “interim” since they are not yet finalized. The IGF guidelines will, according to plan, be finalized during 2012. Hopefully the content of this work could supply the IMO via the IGF working group called BLG (Bulk Liquid Gases), with information and solutions in order to implement bunkering in the future IGF Code.

Truck to Ship bunkering of LNG is a form of LNG transfer and therefore 33 CFR 127 may be used as a guideline. However, 33 CFR127 is focused on large scale LNG transfer from LNG carriers, both for transfer to terminal and for Ship to Ship LNG transfer. Though these guidelines are for large scale LNG, many of the aspects could be used within the LNG bunkering truck to ship project.

The set up of the bunkering procedure described in this Appendix are based upon the OCIMF guidelines considering oil bunkering, in order to get an internationally accepted structure to the document.

The Results

The main aim with this project has been to establish a safe and time efficient truck to ship bunkering procedure for LNG, encompassing the entire bunkering operation, with both the operational bunkering process and the technical solutions that are needed. The bunkering procedure presented in the text below meets this requirement and the complete concept will be accepted and approved in principle by DNV/ABS.

This procedural description over the LNG truck to ship bunkering can be used by authorities and others as input to regulation and guideline work concerning LNG bunkering.

In order to produce a description which was general to fit many needs and different bunkering cases, certain technical solutions which have been developed during this project are not included in the bunkering procedure.

Preface – LNG bunkering truck to ship procedure

This procedure is made for truck to ship bunkering of LNG in a port environment, with a LNG truck delivering the fuel to the ferry. The LNG bunkering of truck to ship in port with demands for short operation time have not been performed before and this procedure has been worked out to handle the specific details of this operation in a safe and secure manner.

This procedure is divided into chapters describing different aspects of the process:

- Chapter 1-4 refers to conditions for bunkering LNG and petroleum
- Chapter 5-7 refers to the Bunkering process
- Chapter 8-10 refers to system and equipment description
- Chapter 11-12 refers to emergency operations and Gas handling

The procedure is made for the transfer of liquefied gases for propulsion purposes (LNG) for fuel only.   This is a general description of a bunkering process and can be used as a guideline for future bunkering projects. There may be additional technical and/or operational solutions which can enhance safety and shorten the bunkering time.

Bunkering Timeline

The timeline used in this project is presented in the picture below. The time limit for the bunker scenario is set to 60 minutes for the complete bunkering truck to ship procedure. In order to more easily distinguish the different actions during the bunkering operation the procedural description is divided in three stages: before, during and after bunkering. These stages are described more thoroughly in the following text.

Glossary

33 CFR127: Code of Federal Regulations for LNG Storage Facility

33 CFR155: Code of Federal Regulations for Vessel Transfer of Fuel

Bunker Truck: a typical articulated tractor trailer with a capacity of 10,000 gallons which transfers liquefied gases to land based tanks and ships for propulsion purposes.

Bunkering Area: an area on the pier and the ship encompassing the bunkering station and pump station on the ferry and manifold on the trailer.

Emergency Shut-Down (ESD): a system to stop the liquid fuel and vapor flow in the event of an emergency and to bring the bunker handling system to a safe static condition.

Exclusion Zone (EX-Zone): European hazardous areas classifications in zones, protection types, temperature codes and codes; the area in which all electrical equipment is intrinsically safe to avoid ignition of LNG vapor.

International Code for the Construction and Equipment of Ships Carrying Liquefied Gases in Bulk (IGC Code): applies to gas carriers constructed on or after1 July 1986

International Code of Safety for ships using gas or other low flash-point fuels (IGF Code): international code for Gas-Fuelled ships.

International Maritime Organization (IMO): specialized agency of the United Nations established in 1948, with headquarters in London and 158 member nations. IMO is one of the smallest of the UN agencies. Originally called the Inter-Governmental Maritime Consultative Organization, it was renamed a decade after its formation. The IMO deals with various aspects of the regulation of international commercial shipping, encouraging cooperation among governments in a wide variety of technical matters. In addition, the agency supports high standards in maritime safety, promotes efficient navigation, and encourages the control and prevention of marine pollution. It has the power to enforce and administer matters relating to these aims.

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Liquefied Natural Gas (LNG): predominantly methane (CH_4) which has been cooled down to approximately-162 deg C and converted to liquid for easier storage and transportation

Marine Diesel Oil (**MDO)** is a blended fuel from gasoil and heavy fuel oil.

Marine Gas Oil MGO: is a fuel made from distillates only.

Receiving Ship (Ferry): A ship which receives liquefied gases from another ship

Rapid Phase Transition RPT: a phenomenon when LNG vaporizes violently in contact with water.

SOx Emission Control Areas SECA: areas with restrictions regarding the amount of sulfur in the fuel.

1. GENERAL PRINCIPLES

1.1 Scope

This procedure is made for truck to ship bunkering of LNG in a port environment, with a dedicated tractor trailer delivering the fuel to client ships. The typical trailer is a LNG Tanker Model T289. The trailer is owned by the Gas Company and the tractor and operator are contracted. The described bunkering operation in this procedure is based on common petroleum and liquefied gas transfers with regards to the specific regulations for LNG within IMO IGC codes and interim IGF codes and technical solutions for safe short time bunkering.

1.2 Control of operations

On each ship there must be one responsible person in charge during the complete bunker operation. This person shall be the Chief Engineer on watch. He/She is to have sufficient education, training and authorization to safely perform the LNG bunkering.

1.3 Responsibility

Each Master is responsible for his own ship, personnel and bunker regarding all safety and other issues for the complete operation. All bunker operations must be agreed upon between the truck and the receiving ship before commencing any actions.

2 CONDITIONS AND REQUIREMENTS

2.1 Approval

Before commencing any bunker operations it is necessary to have authority's approval for LNG bunkering.

2.2 Ship Compatibility

It must be clarified that mooring and bunker equipment are compatible in design so that the bunker operation can be conducted in a safe way before commencing any operations. Following points are to be confirmed by communication:

- Possibility for safe mooring
- The relative freeboard difference
- Type and size of hose connections
- Connection order of the manifolds

2.3 Transfer Area

The transfer area is determined by the local port and approved by authorities (see 2.1). Points to be considered are:

- Maneuvering space

- Tidal conditions
- Waves, swell and weather conditions

2.4 Weather Conditions

Weather and current forecast for the area are to be studied before commencing bunkering operation. Each Master is responsible for his own ship and bunkering is only allowed when both the Master and Chief agree that ambient conditions (like wind and weather) are acceptable. Each Master is also responsible to determine restrictions and take actions in case of a sudden change of ambient conditions during a started bunker transfer.

2.5 Light Conditions

The bunkering operation will be accomplished during the shutdown period overnight without passengers or vehicles onboard the vessel. The shutdown occurs after dark, between 2200 and 0530. Sufficient light is provided at each terminal where bunkering wills occur.

3 SAFETY

3.1 General

The Master and Chief are at all time responsible for the bunkering operation and should not allow safety issues to be influenced by the actions of others. They are to ensure that correct procedures are followed and that safety standards are maintained and that the ship system and procedures are according to approved rules and regulations.

3.2 EX-Zone

The bunkering area is to be an EX-classified and restricted area during bunkering. Only authorized personnel are allowed in these areas during bunkering. Inside the EX-zone all electrical equipment is required to be intrinsically safe and the electric energy should be too low to allow the ignition of LNG vapor. The size of the EX-zone shall be according to the IGF Code for Zone I. The Zone I is within 3M of any bunker manifold valve, flange or gas tank outlet. A hazardous area Zone 2 is an additional 2.5M beyond Zone 1. The electrical equipment in these areas are certified to IEC 60079-10. An exclusion Zone will extend 10 m horizontally on each side of the piping, transfer pump and bunkering station and vertically.

3.3 ESD-System

Each truck and ferry shall have an independent Emergency Shut-Down system for a quick and safe shut-down of the transfer pump and all bunkering system valves in case of an emergency.

3.4 Check-Lists

Each ship is to have internal individual check-lists for before and after bunkering. For the bunkering operation there shall be a common check-list which is to be filled out and signed by responsible operators on the truck and the ferry before any operation is commenced.

3.5 Instructions (Routines)

There shall be written detailed instructions for the bunkering process with regards to responsibility and actions to be made in case of malfunction or emergency. The instructions are to be quickly available at all times and all personnel involved in bunkering operations are to be familiar with the content and location of the instructions. The instructions should cover the following areas:

- Loss of communication or control system (ESD)
- Loss of power
- Handling of cryogenic products including the use of personal protection equipment, ice formation and awareness of sharp edges.
- Waves and weather conditions

3.6 Warning signs

There shall be warning and instruction signs posted around hazardous areas on the ferry. The signs are to be placed clearly visible and according to an accepted guideline for placement of warning signs. The warning signs are to cover the risks of handling cryogenic liquid, fire and safety issues and show restricted areas.

3.7 Safety during Bunker

3.7.1 Smoking and Naked Light

The ferry and ferry terminal are both non-smoking facilities. The use of naked lights shall be strictly enforced. Warning signs and notices shall be clearly posted.

3.7.2 Ground on switchboard

The truck trailer and transfer pump are to have dedicated ground cables attached to the ship for continuity and grounding. The switchboard and bunkering control panel on the ferry shall have ground fault indicator lights to indicate faulty circuits. Any indications of faulty circuits are to be immediately traced and isolated to avoid arcing around bunker area. The bunkering operation is to be suspended in case of a ground fault indication during ongoing transfer.

3.7.3 Electrical Currents

Electrical current and Electrostatic Charge in Bunker Hose

To prevent the occurrence of arcing between the truck and transfer pump manifolds on both ships are to be grounded, all hoses are to be electrically continuous and each hose string shall be fitted with an insulating flange on the truck manifold. It is important that the insulating flange only is fitted to the truck; otherwise there may be an electrostatic build-up in the hose between the insulating flanges which can result in arcing.

Electrical Arcing

Other places (besides hose connections) where arcing can occur are:

- Mooring lines
- Ladders or gangways between the pier and ferry
- Bare wires and chains for fender support

3.7.4 Radio and Communication Equipment

The ships main radio transmissions may cause electrical resonance in insulated parts of some ship fittings arcing such as mast stays and this can cause arcing across deck fittings. Radio aerials should be grounded, but can induce arcing if insulators are coated with salt, dirt or water. The use of ships main radio equipment during transfer operations can be dangerous and should be restricted during the process. The equipment is not to be used if there is possibility of flammable gas in the vicinity of the antennas.

Satellite communication equipment normally operates at low power levels and is considered to be a low ignition hazard. The equipment is not to be used if there is a possibility for flammable gas in the vicinity of the antenna.

VHF and UHF communications are low voltage operated and are considered to be safe to use. Hand-held VHF or UHF radios are to be intrinsically safe (EX-class)

Portable electronic devices such as mobile phones, cameras etc using batteries are not allowed in hazardous areas unless they are EX-class. It is especially important for personnel working in or visiting such areas to be aware of this.

3.7.5 Radar

The radar equipment is not intrinsically safe and can create potentially hazardous power densities. The radar on the ferry shall be secured during all bunkering operations.

3.7.6 Electrical storms

No bunker operation should be commenced during electrical storms. In case of sudden electrical storm appearance during ongoing transfer, the operation is to be suspended and all systems secured until it is considered safe to resume operation.

3.7.7 Fire-Fighting Equipment

Fire-fighting equipment on both the trailer and ferry are to be ready for immediate action. A charged dry chemical portable extinguisher shall be available at the truck manifold, the transfer pump and the bunkering station. The ferry already has a sprinkler system that covers the car deck area and the bunkering station is fitted with a dry chemical system which provides 7.5 lb/sec for 45 seconds. In the case of a fire the bunker station fire system can be activated remotely.

3.7.8 Accommodation Openings

All accommodation openings on the ferry are to be closed during transfer. Personnel transit is not allowed during bunkering unless it is an emergency.

3.7.9 Safety Zone

The ferry shall have a safety zone above the bunker station during bunkering. The extent of the safety zone should be 10 meters on each side of the bunker station manifold. This safety zone shall be clearly marked and have the following restrictions:

- No unauthorized persons to be able to access open deck areas directly above the bunker area
- Warning signs to be posted around the area
- Access doors to be locked and only to be opened by trained and authorized personnel
- No overhead crane lifting in this area during bunkering
- No maintenance work in the area during bunkering
- No maneuvering of ship equipment in the area during bunkering
- Ventilation inlets in the area to be closed during bunkering

3.7.10 Gas Accumulation

Transfer operation shall be suspended if there is fuel vapor leaking around manifolds on the truck, transfer pump or bunkering station. Operation is not to be resumed until leakage is identified and stopped and all gas has dispersed which is monitored by gas detectors at the bunker station.

3.8 Maintenance

Key components in both ships systems are to be identified with emphasis on safety to avoid leakage and ignition sources in and around the bunker areas. These components should have a maintenance and replacement schedule where inspections and actions are documented and stored on board.

3.9 Redundancy

Key components in the ship's control and power systems are to be identified with emphasis on safety in case of failure. These components shall have redundancy back-up which can start up within a short period of time. All control and monitoring systems shall have a redundant power supply in the event of the loss of the primary power source a backup power source will take over without interruption.

3.10 Personnel education and training

All personnel working with LNG bunkering are to be educated, trained and authorized for working with liquefied gases. Non-educated and trained persons are to be classified as unauthorized and are therefore not allowed to be inside bunker area during operation. Education and training records of all personnel are to be kept on board and be available if requested by US Coast Guard or port authorities.

3.11 Personal protection equipment

There shall be personal protection equipment, like gloves, eye protector and protective clothing, for handling cryogenic products at bunkering areas and the personnel involved are to be well instructed where to find the equipment and how to use it. The personnel must wear the following personal protective gear:

- Nomex Coveralls
- Insulated Gloves
- Face Shield
- Safety Boots

3.12 Sharp edges

The bunkering area shall be designed not to have any sharp edges around the bunker stations due to the possibility of damage to the hoses during handling. Loose items with potentially sharp edges, like hand tools, are to be stored outside the direct hose handling area. The hoses shall be set into stainless steel troughs on the deck. The interior surface shall be fair and smooth between the chocks.

4 COMMUNICATIONS

4.1 Language

The English language shall be used for communication.

4.2 Communication between Ships

The communication methods used could be by VHF, hand-held radios, vocally or by a separate communication link depending on the phase of the operation and availability of equipment. There shall also be reliable means of communication at all times during bunkering, such as hand-held VHF. No transfer operations are to begin before effective communication has been confirmed. Optionally there can be a cable link between the LNG trailers, transfer pump, bunkering station and storage tanks.

4.3 Procedure for Communication Failure

Communication failure during bunker operations – Sound the emergency signal and suspend all operations in progress immediately. The operations shall not be resumed before communications has been re-established.

BUNKER PROCESS CHAPTER 5-7

5 OPERATIONS BEFORE BUNKERING

5.1 Preparations

The following steps shall be made prior to start of the operation and noted on the Before Bunker Check-list:

- Safety zone on ferry activated and checked.
- Fire equipment on trailer and ship checked and ready for use
- Personal protection equipment on trailer and ship checked and prepared for use
- ESD system on the ship and trailer checked and ready for use

5.1.1 LNG Tank System Check

The ferry and trailer must check the LNG tanks regarding temperature and pressure prior to bunkering and note this on the pre-transfer bunker checklist. If the temperature of the receiving tank is significantly higher than the bunker tank, there will be an initial vaporization when starting to transfer the LNG. This will increase the tank pressure and can trigger the pressure relief valve to open if the pressure exceeds the set limit. The pressure of both tanks must be reduced prior to the bunkering in case of a high receiving tank temperature. The trailer operator and Chief Engineer are to confirm that both ships combined temperature and pressure range are within the safety limits before commencing transfer.

5.1.2 Mooring Equipment Check

Lines, fenders, winches and other mooring equipment is to be visually checked for wear or damages. Equipment should be replaced or the transfer aborted if there are any doubts about equipment quality and safety.

5.1.3 Bunker Hose Check

Bunker hoses are to be visually checked for wear or damages and that the hose markings are correct for the actual transfer operation. Bunker hoses should be replaced if there are any doubts about equipment quality and safety.

5.2 Check-List Before Bunker

Both the LNG trailer and the Ferry are to have a checklist which contains the steps to be made and documented specific for each ship before the bunkering process commences.

See Appendix A for Check-list “Before Bunkering”.

5.3 Call

The Master shall notify the port of the time and location by the normal VHF contact channel that the transfer of LNG will take place, the working channel for VHF communication, emergency signal and contingency plan (see 11.3) to be agreed upon.

5.3.1 Safe Communication

Safe communication and the possibility of performing bunker operation, due to weather and traffic conditions according to chapter 2, are to be confirmed by the Master.

5.3.2 Arrangement Plan

The ferry shall supply, if requested, a sketch with information about placement of the trailer and transfer pump in relation to the bunker station and storage tanks. The Arrangement Plan shall show the number of lines and dolphins and their locations with respect to the transfer span and location of the shore side approach.

5.3.3 Mooring Operation

When taking weather conditions such as wind and current in account the ferry shall be moored in a safe manner. The bunker station should be placed on the forward section of the curtain plate to ensure a good access on the No 1 End between the transfer span and the bow of the boat, additional lines to should be ready for use if needed.

5.3.4 Mooring Lines Supervision

Mooring lines are to be under supervision during the operation. Special attention is to be given when bunkering a vessel during heavy weather or when other vessels are in the area.

5.4 Connection Communication Link (Option)

Optionally, there can be a separate communication link which is located at the bunkering station. This panel would contain a wired communication system with the following:

- Have a direct line phone system
- View the level, temperature and pressure of the receiving tanks
- Monitor alarms.
- Include the emergency stop control instead of a separate box (see 11.2 & 11.6.3)

5.7 Connection of Hoses

The hoses are to be supported over their entire length from the truck to the transfer pump and from the transfer pump to the bunkering station. All connections and handling of hoses shall be accomplished by trained personnel from the ferry, before operation commences.

Each manifold are to be grounded and the ferry shall be equipped with an insulating flange near the coupling to prevent a possible ignition source due to electrostatic build-up. The hoses with couplings should not touch any un-grounded part before connection to avoid possible electrical arcing.

The hose connections can, if possible, be of different sizes for increased safety reason to eliminate the possibility of error in the connection point.

5.8 Bunker Hoses

5.8.1 LNG Bunker Hose and Vapor Return Hose

The hoses shall lie in a tray made of stainless steel from the trailer to the transfer pump and from the transfer pump to the bunkering station. The trays are 8M in length with a clamp connection on the ends. The hose is supported by plastic chocks located every meter. The hoses shall not come in contact with the steel deck during transfer. The trays are designed to contain any small amount of leakage preventing the LNG from contacting the deck.

5.8.2 Oil Bunker Hose

The oil bunker hoses are to be clearly color-marked so that there will be no risk of using an incorrect hose type. The hoses must be in good condition, have suitable length for the actual transfer and supported to avoid overstressing or chafing during transfer.

5.9 Pre-Transfer Bunker Check List

The pre-transfer checklist is a mutual document with steps to be made on the trailer and ferry, and signed by authorized persons to confirm that all points are addressed. The trailer operator is responsible for the checklist to be properly filled in and signed before delivery to the receiving ship. The Chief Engineer will accept the checklist and issue the order to proceed after alerting the pilothouse that the bunkering is to commence.

6 OPERATIONS DURING BUNKERING

6.1 Return of Documents

6.1.1 Signed Check-List

The pre-transfer bunker check-list are to be filled out, signed by the Chief Engineer on the ferry and returned to the trailer operator before starting any transfer. A copy of the signed check-list is to be kept on board the ferry for a minimum of 3 months. No bunker operations are to begin until this check-list is signed by both parties.

6.1.2 Signed document with Agreed Amount and Transfer Rate

A document, clearly stating the quantities of fuel to be transferred, the transfer rate, start and topping up rate and maximum pressure at manifold, is to be filled out and signed by the responsible persons in both parties. This document can be combined with the pre-transfer check-list mentioned above. The signed document is to be kept on board the ferry for three (3) months.

6.2 Open Manual Bunker Valves

After receiving signed documents the trailer may close the road relief valve set at 30 psig. The main relief valve is set at 75 psig. Pressure is built in the trailer by allowing LNG from the bottom of the tank to flow and vaporize through a pressure buildup coil on the underside of the trailer. Once the pressure in the trailer and the receiving tanks are within 10 psig, it is allowed to first open the manual bunkering valves (line up the transfer path).

It is important to check that the remote controlled bunker valves are closed, by visually checking the valve indicator, prior to opening the manual valves. There shall be one oiler at the bunkering station and transfer pump and a second oiler at the storage tanks to monitor the tanks. The chief engineer shall oversee the operation and will monitor the situation at the communication panel at the bunkering station.

6.3 Ready Signal

When the manual valves are confirmed to be opened and the personnel is confirmed to be outside the immediate transfer zone, the operator and the ferries' oilers confirm that they are ready to commence bunkering by giving a ready signal by VHF or optional communication link. The chief will initiate the bunkering.

Prior opening the valve to the storage tank, the line shall be purged of air by releasing a small amount of LNG into the line and opening the purge valve on the bunkering line and allowing the air to escape up the mast. Allow sufficient time approximately five minutes for the purge to complete and close the purge valve.

6.4 Pump Start Sequence

After ready signals are given and personnel are out of the bunker area, the transfer pumps can be started and ramped up in a controlled manner until the agreed start transfer rate is achieved. This sequence is to be closely monitored on both ships for possible leaks, hose and equipment behavior and system functions. With the trailer and the storage tank within 10 psig, open the vapor return line at the bunker control station and the trailer slowly to allow the pressure in the two tanks to equalize. Once the pressure is equalized the fill line, open the fill line to the storage tank and crack open the tanker liquid withdrawal valve to begin the cool down of the liquid fill line.

Once the lines to the bunkering station are flooded, start the transfer pumps slowly to continue the cool down of the line to the storage tanks. Slowly open the supply valve and increase the speed of the pump. Maintain a tank pressure of 60 psig at both the storage tank and trailer by cooling the storage tank as required.

If any problems, or suspicions of problems, are detected, transfer is to be shut-down immediately and not started again until satisfactory checks and actions are performed. The start sequence transfer rate is to be upheld for an agreed time, giving time for monitoring and also cooling down of the system before the transfer rate is increased.

6.5 Bunkering

When the pump start sequence is completed the transfer pumps can continue to ramp up in a controlled manner until agreed rate is achieved under constant supervision and monitoring of the equipment and the system. This rate can be withheld during the transfer until agreed amount is almost reached. The transfer is to be continuously monitored with regards to system pressure, tank volume and equipment behavior.

6.6 Pump Stop Sequence

The cargo pumps shall be ramped down to an agreed topping up rate when the total transfer amount is almost reached. The final filling requires special attention on the receiving ship to watch tank level and pressure. The maximum level for filling the LNG tanks is 95% of total volume to allow for cooling the tank to accept the residual LNG in the line. The receiving ship operator is to signal, by VHF or optional communication link to the bunkering station when the required amount of fuel is reached. The oiler will then secure the transfer pumps.

7 OPERATIONS AFTER BUNKERING

7.1 Purging of Bunker Hoses

The liquid that remains in the bunker hoses, after the pumps have stopped, must be drained before disconnection. Heated LNG-vapor from the trailer is to be blown through the hose in order to purge the hose. The valves at the transfer pump are to be closed when the purging is completed.

When the bunkering is complete, the vapor return line is closed as well as the liquid fill line at the trailer. The remaining LNG in the line will be push up the line by a buildup of pressure in the trailer with a simultaneous reduction of pressure in the storage tank. The maximum operating pressure of the trailer is 67 psig. The differential pressure required to purge the line of LNG is approximately 18 psi from the bunkering station to the storage tank.

7.2 Close Manual and Remote controlled valves

Once the line is purged of LNG, the valves at the storage tank are to be closed. First the remote controlled valves are to be closed and then the manual valves. The bunkering line purge valve is opened and the line is injected with nitrogen. The vapor return line purge valve is opened and charged with nitrogen. The bunkering line can be purged with nitrogen from either the transfer pump trailer or from the bunkering station. The vent return line is purged from the bunkering station.

7.3 Disconnection of Hoses

The bunker lines and vapor return, on the LNG trailer, can be disconnected after the lines have been purged from liquid, allowed to warm up and valves are closed. With use of protective equipment (gloves and protective clothing), the quick-connect couplings are to be disconnected with attention to possible dripping of fuel. If a second LNG trailer load will be delivered, the hoses between the transfer pump and trailer shall be purged with nitrogen before the first LNG trailer is moved. When the second trailer is in position, a second Pre-bunkering Checklist will be completed prior to the transfer of fuel. There should not be any sharp edges in the hose handling area.

7.4 Disconnection Communication Link (Option)

The communication link, if available, is to be disconnected and returned to the EOS.

7.5 Delivery Bunker Document

The LNG trailer is to deliver a document, in 2 copies, clearly stating the quantity and quality of fuel transferred, signed by the responsible officer. Both copies are to be signed by the receiving ship personnel. One signed document is to be kept by the driver and the other document on board the ferry for three (3) months.

7.6 Inerting of Bunker Lines

The ferry must inert the bunker line and vapor return line before departure, which means that the inerting sequence is to start as soon as the hoses are disconnected from the manifold and run until the lines are gas free. The trailer does not need to inert before departure since the hoses are stored on the trailer and are ventilated. To avoid the risk of forgetting to inert the bunker hoses, there shall be an inerting section in the After Bunker Check-list to be checked out within 10 minutes after departure and an alarm signal on the main switchboard if inerting valve has not been activated within 60 minutes from stopping the cargo pumps.

7.7 Check-list After Bunker

Both the trailer and the receiving ship is to have a checklist which contains steps to be made in order to safely shut down the bunkering system. The checklist shall specifically document the ship and bunkering event after the bunkering process is completed.
See Appendix C for check-list “After bunkering”.

8 EQUIPMENT

8.1 Bunker Hoses

8.1.1 Hose Standards

The hoses used for handling LNG and vapor shall be specially designed and constructed for the products with a storage temperature of – 196° C.

The hoses used for MDO and MGO are more standard type hoses which are available in a larger scale.

8.1.2 Hose Size and Length

All hose strings must have sufficient length to avoid over-stressing and chafing during the bunkering process. To determine the correct hose length, the ships relative freeboard changes and ship movements must be taken into consideration. The hose size is depending on the maximum amount of fuel to be transferred in a defined time frame.

8.1.3 Hose Handling

The hoses shall be handled with great care both during transportation and bunker operations. It is important to keep the hoses sheltered during transportation and to support properly when lifting to avoid damage by kinking. The minimum bending radius (MBR) for each hose must be observed. Each hose section will incorporate caps on each end which will provide an airtight seal to avoid any moisture or other contaminants from entering the hose.

8.1.4 Hose Connection

The hose connections should be drip free and preferably quick-connect coupling in order to have a safe and fast connection/disconnection procedure. This type of coupling has two handles to lift, press and rotate to lock position and is designed for the fuel temperature both for functional and operational reasons.

8.1.5 Hose Inspection and Testing

All hoses shall be part of a specified test program where each hose is to follow a predetermined schedule of inspection, pressure testing and finally replacement. The hoses shall be pressure tested in consultation with the hose manufacturer. This schedule is to be strictly maintained and all information is to be documented and saved on board. The hoses must also be visually inspected before each transfer to detect possible damages during handling. It is very important to monitor the hoses during start-up of the transfer, to verify that there is no leakage which can increase and cause spill.

8.1.6 Marking

Each hose is to be marked according to a specific system. The marking should contain the following information: For which fuel the hose is designed for, manufacturer, maximum allowable working pressure, month and year of manufacture, minimum bending radius and certification number to identify the specific hose in inspection and testing program.

8.1.7 Differential Pressure Measuring

Each LNG bunker hose shall have a differential pressure measuring system connected to the control system. The pressure will drop quickly in case of a hose leakage which will be detected and the control system will activate the safe shut-down procedure (ESD) which will close down necessary valves and the pump + give audio and visible signals on the bunker ship bridge.

8.2 Bunker Station

The bunker station on the ferry is located on car deck along the forward end of the curtain plate. The layout of the bunker station should be standardized with placement of manifolds and size/type of connections to make the bunkering operation quick and safe.

8.3 Break-away Coupling

There shall be a break-away (dry-break) coupling on each LNG hose, placed on the receiving ship's manifold to ensure that hoses do not break in case of extreme movement or emergency. The function of this coupling is to be the weakest part of the chain and to break off if forces exceed the limits. Inside the coupling, there are two quick-closing shut-off valves, which immediately close and prohibit leakage.

8.4 Mooring Equipment

It is important that the ferry has good quality mooring lines, well placed and sufficiently strong fairleads and bollards.

8.5 Lighting

Ferry and terminal lighting is sufficient. Note that all lights around the bunker area are to be of EX-class.

8.7 Trays below manifolds

Insulated stainless steel trays will be provided below the LNG and vapor return manifolds, to prevent damage to the steel hull in case of leakage. Each tray should have an outlet overboard which can be a temporary fitted pipe or hose to lead possible spill to the water without contact to the hull.

8.2 Gas Detectors

There shall be gas detectors installed in enclosed or semi-enclosed spaces around the bunker area. The detectors are to be connected to the control system and give both visible and audio signals at the actual location in case of a detected leakage. The bunker operation shall be terminated in case of gas detection and not be resumed until it is safe to proceed.

8.3 Fuel Quality Measuring (Option)

There may be a need for measuring and documenting the quality and quantity of the LNG bunkered, especially in the case of serving several different customers. The quality could be measured by a Gas Chromatograph, where a small sample is taken and analyzed for its energy value and content. The quantity could be measured by a mass flow meter which continuously monitors the amount being bunkered.

9 LNG CARGO SYSTEM DESCRIPTION

9.1 General

This system description describes the design of a trailer to ferry bunkering system, as well as the safety aspects to consider when dealing with LNG. The different parts of the bunkering system and their function are presented. All equipment for handling cryogenic products are to be calculated and designed to endure the characteristics of the liquid gas and environmental influences like wave motion and other weather related issues.

9.2 Equipment

9.2.1 General data

Specification	**Storage tank Trailer**	**Storage tank Receiving ship**
Design code	NFPA 57	DNV,IMO
Media	LNG/CH_4 Natural gas Methane	LNG/CH_4 Natural gas Methane
Temperature (°°C)	-196 - +50 (-196 for LIN purging)	-196 - +50 (-196 for LIN purging)
Working pressure (bar)	5	9
Gross volume (m^3)	38	(2) 100
Specification	**Inner piping**	**Outer piping**
Design code	NFPA-57	DNV/EN
Media	LNG/CH_4	LNG/CH_4
Temperature (°°C)	-196 - +50	-196 - +50
Design pressure (bar)	16	16

9.2.2 Tanks

The LNG trailer will be equipped with an insulated storage tank type C for liquefied natural gas (LNG). The tank will be able to contain ~10,000 gallons at 4 bar(g) and -163°C. The tank and its piping system will be design to operate over the road. While travelling over the road the pressure in the tank is reduced to 2 bar. The tank is exposed to the weather, which ensures good ventilation.

The ferry will be equipped with two cryogenic LNG tank type C consisting of two tanks; an inner vessel which contains the liquid LNG and a outer vessel/vacuum jacket which is regarded as a secondary barrier. The annular space between the inner and outer vessel, which is filled with perlite is evacuated with vacuum. Compared with other insulation perlite has a good insulating ability even if the space would have “lost the vacuum level”.

LNG filling of the receiving tank will be performed by spray nozzles in the top of the tank as well as a tube for filling at the bottom. This allows the operator to balance the tank pressure.

Filling at the top allows the LNG to cool down and condense the vapor in the tank, which lowers the pressure in the tank.

The principle of level gauging of the tanks is to measure the differential pressure between the top and bottom of the tank. Based on the difference in pressure the amount of liquid in the tanks can be calculated. Differential level transmitters giving 4 to 20 mA are used.

9.2.3 Pumps

The bunkering process utilizes a portable transfer pump located on the Ferry. The trailer incorporates two pumps for redundancy and a source of nitrogen for purging the lines. The pumps are ACD, Model AC-32 Size 2 x 4 x 6. The pumps are mounted on a trailer with a power connection on the ferry. The motors are totally enclosed intrinsically safe motors rated at 7.5 Hp each. The flow will be regulated by variable frequency drive together with flow regulating valves.

9.2.4 Bunker Stations (System)

The bunker station has a two hoses LNG bunkering system. Three pipelines connect the bunker stations with the LNG tanks. One pipeline is for the liquid LNG, which is partly routed in a vacuum insulated pipe. Another pipeline is for the gas return, which is used when bunkering with 2 hoses. The third pipeline is for nitrogen used to inert the lines once the bunkering operation is complete.

In the bunkering operation the vapor return line is closed and the pressure in the trailer is allowed to increase forcing the remaining LNG into the storage tank. By letting LNG evaporate in the tank, a higher pressure is achieved in the tank than in the piping system. The pressure can then be used to push the LNG into the tanks after bunkering (stripping). Once the line is clear of LNG, nitrogen gas is released into the line to clear the remaining gas and inert the pipeline. This method minimizes Nitrogen contaminating the fuel.

9.2.5 Piping System

The piping for the natural gas system on both systems will be an all welded constitution and manufactured entirely in austenitic stainless steel. The systems will be designed to be able to withstand pressure pulsation in the case of an Emergency Shutdown (ESD). The piping system is normally maintenance free under normal operation conditions.

The piping systems (both sides) for bunkering consists of a few main systems, the liquid bunker line, and the gas return line and the nitrogen system. The systems are equipped both with manually and pneumatically operated valves.

The liquid bunker line is equipped with valves and instruments to control the flow, pressure and quality of the transferred liquid. From the liquid bunker line there is a recirculation line, “kick back line”, leading back to the tank equipped with a control valve. The kick-back line allows the system to re-circulate a part of flow from the pump back into the LNG tank to maintain correct pump pressure regardless of the design of the receiving ship. The re-circulated LNG is injected into nozzles at the top of the tank providing a fine spray of LNG causing evaporation and cooling, which in turn reduces the pressure in the tank.

The gas return line is equipped with valves and instruments to control the gas flow back to the bunker tank. Mainly the flow is regulated by bunker tank pressure. The purpose of the return line is to balance tank pressure in the discharging and receiving tanks. By maintaining a balance in the pressure between the two tanks, the required pump head is reduced minimizing the added energy to the LNG product.

There shall be a system for gaseous nitrogen onboard the ships. This is needed for purging the piping system from LNG and natural gas after bunkering (inerting). The manually operated valves, which will introduce nitrogen to the LNG system, are located in the bunker stations. There are also equipment for level and pressure measurement and other safety functions.

9.2.6 Vacuum Insulated Pipes

When bunkering LNG there is an advantage to minimize heat transfer to the liquid. To eliminate heat transfer to LNG, vacuum insulated pipes could be used from the bunker tank to the bunker station and from bunker station to the receiving tank.

9.2.7 Double Trunk Pipes

Double pipe envelopes certain natural gas pipes on the ships. In this case they shall be fan ventilated to discharge possible natural gas leakage to the vent pipe/mast so gas will not be accumulated somewhere on the ship. The manifolds are equipped with gas detectors giving alarm to the ship’s IAS in the case of gas leakage. On the LNG bunkering truck some piping will be on the open deck and have natural ventilation.

9.2.8 Safety Valves

The system includes valves regarded as ordinary safety relief valves as well as so called thermal relief valves. The tanks’ main safety valves are designed to meet requirements for a LNG tank. Thermal relief valves are designed to meet capacities in a trapped volume in pipes. A safety valve exhausts/vents to a vent mast.

To secure that not both safety valves to the LNG tanks are out of operation at the same time, the safety valve system incorporates an “interlock system”. The interlock system consists of lockable valves and a set of keys that permits only one of the safety valves on each tank to be closed.

9.2.9 Vent Mast

There will be the possibility to divert gas from different parts of the system to the atmosphere through a vent mast. The LNG tanks' safety valves will also exhaust to this vent mast, as well as the nitrogen used for purging.

9.2.10 ESD System

Automatic Emergency Shut Down "ESD" systems are required on the Ferry. In the case of an ESD trip different valves and/or pumps will close and shut down parts of the system depending on which alarm that have been tripped.

9.2.11 Control System

The LNG system will be governed by the ship's Integrated Automation System (IAS) computer system. The IAS receives signals from instruments belonging to the system and after evaluating these signals the IAS performs activities depending on which "mode" of operation is chosen.

The pressure of the tanks is governed automatically. Manual mode can be chosen when there is need to by-pass automatic valve control in order to perform special tests with the system regardless if it is in duty/operation or not.

The control system should monitor key components for safety issues regarding overload and overheating and key controls and equipment should have standardized marking.

9.2.12 Electrical & Pneumatic Cabinets

On both the ships there shall be an electric and pneumatic cabinet at the bunker station as well as at the cold box. In the cabinets there are safety barriers to assure that the energy in a cable and instrument always is lower than what is required to ignite a spark. The cabinet has solenoid valves, with a toggle to facilitate manual test possibilities, which provide the actuators on the valves with air. On the electric/pneumatic cabinet at the bunker station there are indicators, which show the tank content and tank pressure in the tanks. ESD valves are delivered with limit switch and solenoid valve mounted on the valve. Pneumatic valves are of the type "fail close". Loss of electrical power or service air will also close pneumatic valves.

9.3 Process

The bunkering process starts with the connection of the communication link between the EOS and the bunkering station. Then the hoses for the transfer of LNG between the ships shall be connected; the liquid filling hose and the gas return hose. The reason there is need for two hoses is to be able to handle the raise in pressure that will occur in the receiving tank. Gaseous natural gas is led back to the trailer through the gas return hose, balancing the pressure in the two tanks allowing the transfer pumps to operate at a lower load.

The transfer pump on deck is controlled by a variable frequency drive. The frequency converter, together with the “kick back line” on the piping system, allows the bunkering truck to adjust the flow of LNG. The flow is further controlled with flow meters flow regulating control valves.

Pressure, flow and temperature transmitters are placed on both the trailer and the ferry to monitor the bunkering process. Close by the bunkering stations there will be an electric cabinet with indicators.

When the level indicator for the ferry indicates that the required level is reached the bunkering shall end. After the bunkering, the piping system and hoses must be purged with nitrogen. Both the ferry and the transfer pump trailer shall have a nitrogen supply to be able to perform purging. However, before using the nitrogen any residual liquid in the system shall be pushed back into the tanks. This is performed using the tank on the LNG bunkering truck, which contains natural gas with a higher pressure then the rest of the system. As that natural gas is released into the system the liquid is flushed from the system into the storage tank. Now the hoses can be disconnected between the ships.

When the hoses are disconnected the nitrogen is let into the piping system close to the tanks; any natural gas is then purged from the system to the vent masts.

10 ESD PHILOSOPHY

10.1 ESD Analysis

The main purpose of the “ESD” Emergency Shut Down system” is to shut down ignition sources to reduce the risk for an explosion in case of gas leakage during the bunkering process. The bunkering process for the receiving ship is regarded as terminated when so according to the receiving ship’s User Manual. The bunkering process for the bunker ship is regarded as terminated when so according to the bunker ship’s User Manual.

10.2 The Ferry

The gas system onboard this ship is assumed to be of the same type as gas systems delivered today for gas fuelled ships. Procedures are foreseen to be enchanted to meet refined requirements as available time for bunkering. The following main parts can be identified:

- LNG tank type “C” with a cold-box (tank room) including product (VAP) and
- pressure build up (PBU) vaporizer
- bunker station
- pipes from bunker station to the cold-box
- pipes from the cold-box to the gas engines
- Nitrogen (N_2) for inerting stowed or generated onboard or supplied from ashore

This implies that the ship and gas system comply with IMO’s rules for gas fuelled ships in all respects as gas detection, fire detection, ventilation, double piping, trunks, etc. Existing gas fuelled ships bunker today from ashore based fixed or mobile system according to existing procedures described in the User Manuals for these LNG receiving ships. The LNG is usually transferred from the supplying tank by a cryogenic pump or by the pressure in the supplying tank. Power management, redundancy and control system for the ship is fully covered by existing class requirements.

10.4 The Tank Trailer

The tank trailer is an articulated tractor trailer. There has not been built a dedicated LNG bunker ship as today but the gas system onboard can be assumed to include gas systems delivered today for gas fuelled ships and LNG carriers. The following main parts can be identified:

- LNG tank type "C"
- Bunker station with valves and equipment
- Cargo Transfer Control system

The gas system complies with NFPA 57 for liquefied gas carriers in all respects as gas detection, fire detection, ventilation, double piping, trunks, etc. Existing LNG carriers bunker today from ashore based fixed or mobile system according to existing procedures described in the User Manuals for these carriers. The LNG can be transferred from the supplying tank by a cryogenic pump or by the pressure in the supplying tank if it is high enough. The pump alternative requires a more refined control and shut down system to protect the pump. Power management, redundancy and control system for the ship is fully covered by existing class requirements.

10.5 Transfer Interface when Bunkering

LNG is transferred from the tank trailer to receiving ship through the liquid fill line. The gas return line from the receiving ship to the trailer serves the purpose to equalize the pressure in the receiving ship and bunker ship. The gas return line can be used if the pressure in the receiving ship and bunker ship are compatible. This implies that the maximum pressure ratings for both tanks are the same. Common practice today when bunkering gas fuelled ships (excluding carriers) is not to use a gas return line. The following bunkering interface areas can be identified:

- The bunker station on the ferry is located on the car deck near the bow inside of the curtain plate. The gas detection is active when bunkering.
- The bunker station on the trailer is located at the back of the trailer with a sheltered area.

- The liquid hose connection on the trailer. The liquid hose is generally quick connected with a break-away type coupling and the hose has a dedicated stowed position when not in use.
- The gas return hose connection on the trailer. The gas return hose is generally quick connected with a break-away coupling and the hose has a dedicated stowed position when not in use.

- A break away coupling is mounted on all hoses on ends connected to the ferry. In case of out of limit and/or uncontrolled movements/displacements by the ferry and trailer hoses will be released from the hose connection on the receiving ship. The breakaway couplings are drip free.
- The receiving ship and bunker ship have instrumentation on both sides of the LNG hose.
- Ship movements and displacements between receiving ship and trailer.
- Hose handling.
- System and control communication.
- Human communication.
- Bunkering area and adjacent phenomenons are not regarded in this ESD philosophy. They are viewed elsewhere.

10.6 ESD Philosophy

In case of a hazardous situation concerned systems will be shut down by an “ESD” Emergency Shut Down system”. The objective is to eliminate ignition sources to reduce the risk for an explosion in case of gas leakage during the bunkering process. Uncontrolled cold LNG flow can cause personnel and structural damages. Individual documents and plans for both ferry and trailer are made indicating gas hazardous zones with gas detectors and ventilation. These documents are essential since the ferry is unloading and loading at the same time as when bunkering. The following can initiate an ESD shutdown:

- pressure
- flow
- temperature
- loss of instrument pressure
- loss of electricity
- pump failure
- gas detection
- fire detection
- ventilation
- out of range ferry and trailer drift/displacement
- manually initiated shutdown

Levels for alarms can be found in DNV’s “Gas fuelled engine installations” chapter control, monitoring and safety systems. Gas systems are controlled and monitored by the ships IAS systems. These systems can generally be monitored and controlled independently at the bridge and engine control room. There is also an independent ESD panel. At the bunker station on the receiving ship there is an emergency stop button. The receiving ship and bunker ship have their own independent ESD philosophy that initiates ESD shutdowns in addition to what is initiated by the transfer interface. To be noted is that generally there are no gas detectors in the bunker station area effective during bunkering. A water curtain covering the bunkering area to mitigate damages in case of LNG leakage can be used.

11 EMERGENCY OPERATIONS

11.1 Emergency Signal

There shall be an agreed upon emergency signal between the ferry and the trailer, like in IMO resolution A 830, which shall be activated in case of an emergency. All personnel should then take actions and proceed according to the contingency plan.

11.2 State of Readiness for an Emergency

The ferry is to be at a high state of readiness at all times during bunkering operations. Following arrangements should be made:

- ESD-system tested and in operation mode
- Emergency stop box (or Link) should be available at the bunkering station
- Fire-fighting equipment ready for immediate use
- Ships prepared to disconnect hoses at short notice
- Axes placed at bunker ship mooring stations for quick release of mooring lines
- Soft rope mooring lines (or tails) for easier emergency cutting
- Ships to have main engines ready for immediate use
- Outlet from LNG spill trays to be led overboard and away from hull
- There is a possibility to have a water curtain system which, in an emergency situation, sprays water over the curtain plate around the bunker stations to protect the hulls from direct LNG contact

11.3 Contingency Planning

Due to the risk for accidents and the potential consequences, it is required that the ferry has contingency plans for dealing with emergencies. A contingency plan is a summary of individual emergency procedures and shows emergency duties for all ship personnel. The contingency plans should be integrated with port and local authorities and agreed upon prior to commencing operations. The following emergencies are example of sections in the contingency plan:

- Fire
- LNG leakage
- Hose failure
- Hose quick release arrangements
- Mooring line failure
- Communication failure
- Personnel injuries (frost burns, suffocation etc.)
- Emergency departure procedure

The emergencies are to be evaluated to see if some of the risk scenarios are more likely to occur, which should be included in the contingency plan.

11.4 Emergency Situations

In an emergency, the Master should evaluate the situation and act accordingly, bearing in mind that too hasty decisions can make the emergency worse. The following actions should be made, step by step, in case of an emergency:

1. Sound the agreed emergency signal
2. Activate ESD-system to stop the transfer
3. Initiate emergency procedures
4. Alert the whole crew
5. Send mooring personnel to stations
6. Notification to port
7. Notification to authorities, if necessary
8. Purge bunker hoses with nitrogen
9. Disconnect bunker hoses
10. Confirm that engines are ready for immediate use

11.5 Safety Drills

Various emergency events can be contained and minimized by using safety drills according to a specified system. The ship crews should frequently exercise fire and safety drills with demonstration of equipment. All personnel should be well informed about their duties and the location of emergency stations and other points of interest for safety reasons for both crew and passengers.

11.6 Advice on some Emergencies

11.6.1 Procedures for Communication Failure

Communication breakdown during the transfer should lead to immediate suspension of all operations and sounding of the emergency signal. Operation shall not be resumed before communication is restored.

11.6.2 Activation of Emergency Shut-Down Systems (ESD)

Activation of the ESD-system includes stopping of the transfer pumps and closing of the bunker valves on both the trailer and the ferry. ESD actuators are to be located at strategic locations around the bunker area to provide a quick shutdown in case of emergency. The trailer should preferably provide an emergency stop to the ferry in order for both operators to be able to stop the pumps. The pipe system is to be designed to handle quick closing of valves (bypass to avoid dangerous pressure surges).

11.6.4 Procedures for Leakage / Gas Accumulation

Bunker operation is to be stopped and ventilation shut off in case of a minor LNG leakages. There are stainless steel spill trays below both manifolds where possible LNG spill will vaporize. The vapor cloud size will depend on the size of the leakage.

Transfer operation shall not be resumed before the leakage is corrected and the vapor cloud has dispersed, which is monitored by gas detectors at the bunker stations.

11.6.5 Accidental LNG Bunker Fuel Release

The bunker operation is to be stopped immediately, ventilations on both ships shut off and port officers notified in case of a major LNG release. There are stainless steel spill trays below both manifolds with a lead overboard to direct any possible LNG spill away from the hull and into the water where it will vaporize which can cause RPT (Rapid Phase Transition) if the spill amount is large enough. Depending on the size of leakage, the vapor cloud size may be significant as LNG expands 600 times in volume from liquid phase to vapor. A major leakage may lead to hull damages if the cold LNG comes in direct contact with the steel. This is not critical for the ships immediate safety, but will require instant repairs at a shipyard.

A LNG release must be reported to the port and authorities. Further transfer shall not be resumed before the reason of leakage is corrected and no damages are reported. Agreement for continuation is made with port and authorities.

12 GAS HANDLING

12.1 General

This gas handling descriptions explains the properties of LNG and natural gas, as well as the dangers of handling the gas and the precautions needed to be taken.

12.2 Safety Information

12.2.1 Cryogenic Liquids

A cryogenic liquid is defined here as a gas that has been liquefied through cooling. A gas is technically defined as being cryogenic when it has been cooled to a temperature below - 160°C at normal atmospheric pressure and has liquefied. The gases in liquid state dealt with in the LNG road tanker loading station are natural gas (which consist mainly of methane) and nitrogen (for pre-cooling).

Cryogenic liquids are classified as dangerous substances and must be handled according to strict rules. It is of great importance that all personnel receive the appropriate training to ensure the safe handling of cryogenic liquids.

12.2.2 Risks when inhaling Methane (CH_4) Natural Gas

Methane, which LNG predominantly consists of, is low toxic when inhaled and has in general no specific physiological symptoms. However, the substance is suffocating and the effect is proportional to the decrease of the partial pressure of oxygen in the inhaled air, which is established when mixing methane and air.

When the oxygen content has decreased to three quarter or less of the normal content asphyxia will occur. The human body will interpret this as oxygen deficiency and reacts (at concentrations 50% by volume methane in air) with obvious suffocation symptoms like difficulties in breathing and rapid breathing at the same time as the ability to respond deteriorates and muscle coordination weakens. Severe cases (by concentrations of 75% by volume methane in air) can lead to unconsciousness and death.

It is therefore of utmost importance that all confined spaces where someone is to enter are sufficiently and thoroughly purged with air in a planned manner and that the oxygen and hydrocarbon content is measured before entering the space. This applies for spaces where an unintentional exhaust might have occurred.

Asphyxia is devious in the sense that it comes sneaking and the victim seldom notices it before too late. By asphyxia the victim is quickly taken out into fresh air and given oxygen or artificial respiration.

12.2.3 Risks when inhaling Nitrogen (N_2) Gas

Nitrogen is used for purging of equipment; either before dismounting, to get it free from natural gas, or after it has been opened for maintenance, to get it free of air and humidity. It is also used for purging of hoses.

Liquid nitrogen (-196°C) can be used for pre-cooling and low temperature testing of equipment before taken into use with LNG. Release of liquid nitrogen leads to formation of a large volume of gas as the liquid evaporates. If nitrogen is released in quantity in a confined space the oxygen content of the air may drop radically, causing an acute risk of asphyxiation. Increased N_2 content do not affect the respiratory system, which means that unconsciousness and asphyxiation occur without warning.

12.2.4 Fire

Natural gas is highly hazardous for fire and explosion. The explosion limit for natural gas is 5 – 15 percent by volume in air at 20 °C. Natural gas is odorless- and colorless.

For a fire or an explosion to occur three conditions have to be fulfilled:

- An igniting spark (a certain amount of energy)
- Combustible material
- Oxygen

As natural gas is combustible and there is oxygen in the air, only an igniting spark is required to establish a fire in the event of a natural gas leakage. An igniting spark can be established for instance by a metal tool hitting a pipe.

12.2.5 Risks when in contact with Cold items and Gas

Methane (LNG) or nitrogen (LIN) in liquid state or cold gas can generate severe chill injuries on tissue and eyes. These chill injuries remind a lot of burn injuries. Bear in mind, that even touching equipment like pipes that are or have been in contact with LNG or LIN, can generate much more severe chill injuries than the liquid itself. If methane or nitrogen in liquid state comes in contact with objects that have a higher temperature than the liquid, furious boiling will be encountered and the temperature of the object will decrease rapidly (Boiling temperature for LNG at normal atmospheric conditions is -160 °C and for LIN it is -196 °C). Human tissues exposed to chill injuries are rinsed in abundance with water of temperature not higher than that of the human body. Warming up with warm water or rubbing makes the wound worse.

12.2.6 Personal Protection

It's essential to use protective gloves for the hands, goggles for the eyes and cover the skin (face shield) where the possibility of contact with liquid, cold pipes and cold equipment or cold gas exists. Gloves should be leather (not rubber). Shoes or boots should not have open metal items as these can cause sparks. To prevent electrostatic charge build-up in the human body all footwear should be made of conductive or dissipative material to allow continuous grounding. Use ear protection against noise from safety valves.

12.2.7 Vapor Fog, Mist

When exhausting/venting cold gas in air they mix, and as a consequence of the lowered temperature mist will arise. The mist is often the cause of injuries, as people escaping from compartments stumble over different objects due to lowered visibility. Release of gas in liquid state leads to formation of a large volume of cold gas as the liquid evaporates, resulting in large formation of mist.

12.2.8 Trapped Liquid

If liquefied gas is trapped in a pipe between two valves or a tank without an exit, the pressure in the tank or pipe will rise till the pipe or tank bursts. The consequence can be severe injuries on personnel. All pipe sections and tanks must therefore be secured with thermal relief valves. If the system is due for modification, you always have to bear in mind the possibility of trapped liquid in a pipe system between two valves. Mistakes can lead to fatal consequences (tube cracking).

12.2.9 Training

All personnel shall be well trained for their duties, as faulty operation can cause damage to equipment and above all to people’s health. Training in taking care of injured personnel, how to take care of damaged equipment and fire fighting has to be attended to regularly. Just as vital as to perform the training is to check the result from the training, and that the training continues till an acceptable level of the training has been achieved.

References

Reference is made to international rules set up by IMO, classification rules and national legislation and guidelines as applicable:

1. Ship-to-Ship Transfer Guide (Liquefied Gases) ICS / OCIMF / SIGTTO
2. Ship-to-Ship Transfer Guide (Petroleum) ICS / OCIMF
3. IGC Code IMO
4. IGF Code (Interim) IMO
5. SOLAS IMO
6. MARPOL 73/98 IMO
7. STCW 78/95 STCW
8. Rules for “Gas fuelled Engine Installations” DNV
9. Port Regulations Gothenburg Harbour
10. Standard Marine Communication Phrases IMO
11. ESD arrangements & linked ship/shore systems for liquefied gas carriers SIGTTO
12. Swedish Civil contingencies agency – MSB, Swedish regulations on land
13. Swedish transport agency – maritime department, Swedish regulations at sea